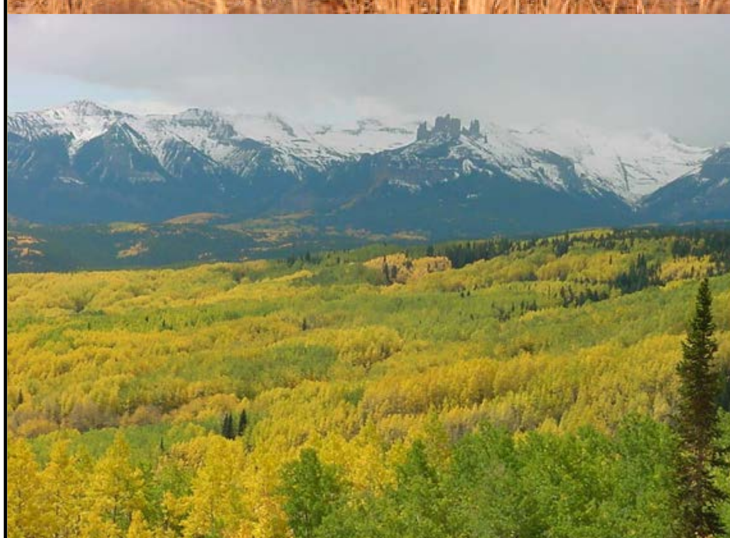
GUNNISON BASIN

CLIMATE CHANGE VULNERABILITY ASSESSMENT

For the

Gunnison Climate Working Group






December 31, 2011

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Executive Summary

Climate change is already changing ecosystems and affecting people in the southwestern United States. Rising temperatures have contributed to large-scale ecological impacts, affecting plants, animals, as well as ecosystem services, e.g., water supply. The climate of the Gunnison Basin, Colorado, is projected to get warmer over the next few decades as part of a larger pattern of warming in the western United States. Natural resource managers need to understand both past and potential future impacts of climate change on land and water resources to help inform management and conservation activities. The goals of this vulnerability assessment are to identify which species and ecosystems of the Gunnison Basin, Colorado, are likely to be most at risk to projected climatic changes and why they are likely to be vulnerable. This report is intended to help natural resource managers set priorities for conservation, develop effective adaptation strategies, and build resilience in the face of climate change.

Vulnerability is the degree to which a system or species is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. In this report, we focus on exposure and sensitivity to describe vulnerability. Exposure is the character, magnitude, and rate of climatic change a species or system is likely to experience. Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by expected climate variability or change. Vulnerability ratings of ecosystems are defined as the proportion of the ecosystem at risk of being eliminated or reduced by 2050 as a result of climate change. For species, vulnerability ratings are defined as the species' abundance and/or range extent within the Basin likely to decrease or disappear by 2050.

This report summarizes the results of a landscape-scale climate change vulnerability assessment of the Upper Gunnison Basin (above Blue Mesa Reservoir; referred to as Gunnison Basin in this report) to determine the relative vulnerability of 24 ecosystems and 73 species of conservation concern, using methods developed by Manomet Center for Conservation Science and NatureServe. The report also summarizes the results of a social vulnerability and resilience assessment of ranching and recreation sectors in the Basin.

Gunnison Climate Working Group

The assessment was developed for the Gunnison Climate Working Group, a partnership of public and private organizations working to build the resilience of species and ecosystems so that they continue to provide benefits to people of the Gunnison Basin. The Working Group goals are to understand the potential threats posed by climate change, identify strategies to reduce adverse impacts, and promote coordinated implementation of these strategies. The Working Group includes representatives from: Bureau of Land Management, Colorado Natural Heritage Program, Colorado Parks and Wildlife, Gunnison County, Gunnison County Stockgrowers Association, National Park Service, National Center for Atmospheric Research, Natural Resources Conservation Service, Rocky Mountain Biological Laboratory, The Nature Conservancy, US Fish and Wildlife Service, US Forest Service, Upper Gunnison River Water Conservancy District, Western State College and Western Water Assessment, University of Colorado, Boulder.

The Working Group is collaborating with the Southwest Climate Change Initiative (SWCCI), whose aim is to provide climate adaptation information and tools to conservation practitioners in Arizona, Colorado, New Mexico and Utah. The Gunnison Basin is one of four SWCCI landscapes developing and testing ways to sustain natural resources in a changing climate. Collaborators include: Climate Assessment for the Southwest (University of Arizona), National Center for Atmospheric Research, The Nature Conservancy, Western Water Assessment (University of Colorado, Boulder), Wildlife Conservation Society, US Forest Service, and the University of Washington.

Changing Climate

Seasonal and annual temperature and precipitation changes were examined and used in assessing the vulnerability of species and ecosystems. The average annual temperature of the Upper Gunnison Basin is projected to increase by approximately 3°C (5.4°F) from the late 20th century to the middle 21st century. Average summer temperatures are projected to increase by approximately 4°C (7°F). Climate projections show no distinct trends in average annual or seasonal precipitation, but they reveal several ecologically important changes, including a 10-25% decrease in average annual runoff, more precipitation falling as rain rather than snow, earlier snowmelt and spring runoff peaks, and changes in the seasonality of flooding. Rising temperatures are projected to bring about these hydrologic changes no matter how precipitation patterns change in the basin (precipitation projections are considerably less certain than temperature projections). These changes underscore the critical need to assess and prepare for ongoing and projected climate change impacts to ecosystems and species in the Gunnison Basin.

The timeframe for this vulnerability assessment is the mid-21st century (2040-2069), as near-term projections of climate change scenarios are largely based on past greenhouse gas emissions and thus have a higher degree to certainty than longer-term horizons.

Ecosystems

Twenty-four ecosystems (17 terrestrial and seven freshwater) were evaluated for their relative vulnerability to climate change in the Gunnison Basin. Fifty percent (12) of the 24 ecosystems were ranked as vulnerable to climate change. Five of the 17 terrestrial ecosystems evaluated were ranked as *highly* vulnerable and five were ranked as *moderately* vulnerable. Four of the seven freshwater ecosystems evaluated in this assessment were ranked as vulnerable to climate change (one *highly* vulnerable and three *moderately* vulnerable).

Five terrestrial ecosystems—mesic alpine, xeric alpine, bristlecone pine, Douglas-fir, and low-elevation riparian—were rated *highly* vulnerable to climate change. The alpine ecosystem is likely to be highly susceptible to rising temperatures and a shorter duration of snow cover. Warmer temperatures and a longer growing season in the alpine may allow shrubs and trees to encroach. For many species, a range shift in response to warmer temperatures is expected, but with no higher areas available for alpine species, a range shift may not be possible. The bristlecone pine ecosystem is limited in distribution and, while higher habitat may become available as the climate changes, bristlecone pine recruits very slowly and may not be able to successfully colonize these areas. Moreover, bristlecone pine may become more susceptible to white pine blister rust. Douglas-fir forests, occurring primarily on cold north-facing slopes, may be significantly vulnerable to increased frequency and duration of insect attacks associated with warming. Low-elevation riparian ecosystems are vulnerable to changes in timing of snowmelt, flooding, and increased invasive species.

Five terrestrial ecosystems – spruce-fir, lodgepole pine, aspen forests, mid-elevation riparian, and irrigated hay meadows – were rated *moderately* vulnerable. Increased droughts and warmer temperatures may increase mortality of spruce-fir forests from bark beetles and root diseases. Lodgepole pine is also vulnerable to pest attacks, particularly mountain pine beetle, as conditions become warmer, especially in winter. Drought may increase the frequency and severity of stand-replacing fires and lethal insect outbreaks in lodgepole pine forests, reducing the integrity and extent of this type. Aspen is particularly sensitive to drought; long-term droughts may reduce the size and/or impair the ecological functioning of aspen stands, especially at lower elevations. Mid-elevation riparian ecosystems and hay meadows are vulnerable to increased invasive species, drought, and decreased base flows.

Of the seven freshwater ecosystems assessed, one – montane groundwater-dependent wetlands – was rated *highly* vulnerable. These wetlands are already adversely affected by water development, grazing, and invasive species, and these stresses are expected to be exacerbated by climate change. Three freshwater ecosystems—mid-sized streams, rivers and reservoirs/associated wetlands—were rated *moderately* vulnerable. Mid-sized streams and rivers were rated highly vulnerable to changes in timing and magnitude of snowmelt and decreases in base flows. Reservoirs were rated highly vulnerable to invasive species and to the fact that they are restricted to specific hydro-geomorphic settings (i.e., they cannot move). High-elevation freshwater ecosystems were ranked *low to moderately* vulnerable, based on their current good condition, high level of protection and management, and high level of connectivity with other systems. Unlike their terrestrial high-elevation counterparts that are vulnerable to rising temperatures, drought, insect outbreaks and damaging wildfire, these ecosystems are expected to remain cold enough to resist pathogens and invasive species.

Key factors contributing to the vulnerability of terrestrial ecosystems include increased pest attacks, increased invasive species, barriers to dispersal ability, fire and drought. Key factors contributing to the vulnerability of freshwater ecosystems include decreasing base flows, dependence on timing and magnitude of snowmelt, and restriction to specific locations on the landscape.

Species

Seventy-four percent (54 out of 73) of the species of conservation concern analyzed were rated vulnerable to projected climate change in the Gunnison Basin: 43 (of 50) plants and 11 (of 23) animals. Most of the species rated as vulnerable occur within the freshwater, alpine, spruce-fir and sagebrush ecosystems. The most vulnerable groups are plants, amphibians, fish, and insects; the least vulnerable groups are mammals and birds. This trend is not surprising, given the comparatively limited dispersal ability of plants and small animals such as amphibians and insects, and the dispersal-limiting restriction of fish to aquatic habitats. More mobile species – birds and mammals – scored as less vulnerable overall. Only four out of 10 birds and three out of nine mammals rated *highly* vulnerable. The most vulnerable birds are Boreal Owl, White-tailed Ptarmigan, Brown-capped Rosy-finch, and Gunnison Sage-grouse. The first three of these species thrive in cooler environments of high elevations, habitats likely to become degraded as conditions become warmer. Sage-grouse require mesic conditions for brood-rearing; these habitats are predicted to become less suitable for this critical life stage.

The most vulnerable mammals are lynx, snowshoe hare, and American pika – all high elevation species with vulnerability scores driven by their limited capacity to adapt to warmer temperatures. These limitations varied from physiological (overheating), mismatches of seasonal coloration due to novel conditions (generally limited or delayed snow), increased competition, and declining habitat area. Over half the birds and two-thirds of the mammals are *presumed stable* or *likely to increase* with predicted climate changes. The wide-ranging bighorn sheep, which has good dispersal ability, is *likely to increase*. In addition to its dispersal abilities, this species may be favored if increased fire frequency creates more open habitat.

Forty-three of the 50 plant species of concern assessed were rated vulnerable (*extremely, highly* to *moderately* vulnerable) to climate change. Examples include Gunnison milkvetch, the moonworts, round-leaf sundew, Colorado wood-rush, and Avery Peak twinpod. Most of these species have not been well studied, so much uncertainty exists with respect to their habitat requirements and climate adaptations. Factors most likely to contribute to the vulnerability of plants include: poor dispersal capability, restriction to cool or cold environments, limited physiological thermal niche, restriction to uncommon geologic features or substrates, and dependence on ice and snow.

Social Sectors

Climate change will likely affect both livelihoods and ecosystems in complex and interconnected ways. In order to develop effective strategies for reducing the adverse effects of climate change, land and water managers need to understand how ecosystems and livelihoods might respond to changes and what types of opportunities and challenges arise from these dynamics. The ranching community has adaptive strategies for dealing with extreme and variable climate, a strong social network, and a long history in the region. However, they are vulnerable to climate change because they depend on public lands and have multiple stressors that challenge their ability to continue operating solely as ranchers. Increased duration and intensity of droughts may place additional stress on area ranches. Current land ownership patterns may make it difficult to expand or change operations in response to climate variability and change. Recreation businesses are dependent on regional and national economic conditions that are not under their control. Climate impacts in other locations may increase recreation pressure in the Gunnison Basin.

Data Gaps

We do not know precisely how the climate will change or how ecological or human systems will respond to climate change in the Gunnison Basin. We also lack complete understanding of inter-specific interactions, genetics, and adaptive capacity of species to climate change. Specifically, life history information and relationships among rare plants, symbiotic species (e.g., mycorrhizae and pollinators), and seed dispersers are poorly understood. Rapid adaptation is possible in some plant species, but there are few data on the subject, especially for the at-risk plants in the Basin and their close relatives. Data gaps also include indirect effects of climate change (i.e., climate change effects on one species that drive changes in other species) and interactions between changing climate and other stressors (e.g., habitat fragmentation). Though recent studies have produced abundant information about the response of some species to the warming temperatures over the past few decades, information about climate-related changes in phenology, distributional shifts, and alteration of habitats of the majority of the Basin's plant and animal species is lacking.

Conclusions and Recommendations

This vulnerability assessment is a first attempt at identifying ecosystems and species of the Gunnison Basin likely to be affected by climate change and why they are at risk. It shows that many of the natural features of the Basin are susceptible to loss, degradation or other changes induced by warming temperatures. Climatological, ecological, hydrological and socio-economic projections suggest that the natural environment of the Basin will change significantly over the next several decades, impacting ecological systems, species and livelihoods.

Climate change projections are highly dependent on emissions scenarios – the volume of greenhouse gases produced by society – for the next several decades. Moreover, the spatial resolution of global climate models is limited. Therefore, uncertainty remains about future local climate, and, accordingly, about how species fitness, population stability, and ecosystems will be affected. While it is important to fill key data gaps and reduce uncertainty about climate change impacts, the climate is already changing, and its ecological effects are already emerging. Given the current high rate of greenhouse gas emissions – far higher than projected only a few years ago – these changes are likely to accelerate and to cause significant changes in ecosystems and the local economy. Accordingly, we need to begin taking action, building on what we currently know, to help to build resilience of the species, ecosystems, and people facing a changing climate.

This report provides a scientific foundation for the Gunnison Climate Working Group's next step to develop adaptation strategies to help species, ecosystems and people adjust to a changing climate in the Gunnison Basin. These adaptation strategies may change the priority, rate, timing, or location of specific actions in the management of natural resources, ranches, and recreation, etc. An important next step will be to integrate the ecosystems and species results with the social vulnerability/resilience assessment. This step will help the Working Group develop a robust set of strategies to reduce the adverse effects of climate change on people and ecosystems, especially where climate change impacts are inter-related. Finally, planning should not stand in the way of natural resource managers and private landowners from taking action that will begin to build resilience. Some high priority strategies have begun to emerge through planning, such as this vulnerability assessment. Implementing these "no-regrets" strategies should continue as the Working Group works to refine and determine additional high-priority strategies.

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Citation: Neely, B., R. Rondeau, J. Sanderson, C. Pague, B. Kuhn, J. Siemers, L. Grunau, J. Robertson, P. McCarthy, J. Barsugli, T. Schulz, and C. Knapp. Editors. Gunnison Basin: Vulnerability Assessment for the Gunnison Climate Working Group by The Nature Conservancy, Colorado Natural Heritage Program, Western Water Assessment, University of Colorado, Boulder, and University of Alaska, Fairbanks. Project of the Southwest Climate Change Initiative.

Acknowledgements

We greatly appreciate the members of the Gunnison Climate Working Group for providing direction, information, feedback, and review of this vulnerability assessment. Joseph Barsugli (Western Water Assessment-WWA) and Jamie Robertson (The Nature Conservancy-TNC) prepared the climate section. Renée Rondeau (Colorado Natural Heritage Program-CNHP), Colorado State University prepared the terrestrial ecosystems section, and John Sanderson (TNC) prepared the freshwater ecosystems section. Lee Grunau, Bernadette Kuhn and Renée Rondeau (CNHP) wrote the plant section. Jeremy Siemers and Lee Grunau (CNHP), and Chris Pague (TNC) wrote the animal section. Jamie Robertson and Karin Decker (CNHP) provided spatial analyses and maps. Special thanks to Patrick McCarthy (Southwest Climate Change Initiative, TNC) for invaluable guidance and support; to Joseph Barsugli for providing climate analyses, data and participating in the workshops; to Linda Mearns (National Center for Atmospheric Research-NCAR) for providing climate models and interpretation; to Jim Worrall and Suzanne Marchetti (US Forest Service-USFS) for providing forest species analyses and models; to Corrie Knapp (University of Alaska, Fairbanks-UAF) for providing the social resilience and vulnerability section; and to Gay Austin (Bureau of Land Management-BLM) for providing invaluable expertise and information on plants. We thank Tim Sullivan (TNC) for his support of this project.

The following individuals provided valuable information and input to the terrestrial ecosystems assessment: Gay Austin (BLM), Mike Babler (TNC), Mike Battaglia (USFS RMRS), Theresa Childers (National Park Service-NPS), Jonathan Coop (Western State College-WSC), Karin Decker (CNHP), Kelly Homstad (BLM), Mary Huffman (TNC), Barry Johnston (USFS), Linda Joyce (USFS RMRS), Corrie Knapp (University of Alaska, Fairbanks), Paula Lehr (Gunnison), Suzanne Marchetti (USFS), Roy Mask (USFS), John Murphy (USFS), Al Pfister (Fish and Wildlife Service-FWS), Claudia Regan (USFS), Renée Rondeau (CNHP), John Scott (Natural Resources Conservation Service-NRCS), Terri Schulz (TNC), Tom Schreiner (Colorado Parks and Wildlife-CPW), Liz With (NRCS), and Jim Worrall (USFS).

The following individuals provided valuable information and insights to the freshwater assessment: Gay Austin (BLM), Joe Barsugli (WWA), Ian Billick (Rocky Mountain Biological Laboratory-RMBL), Dan Brauch (CPW), Andrew Breibart (BLM), Steve Glazer (High Country Citizens Alliance-HCCA), Carol Howe (USFS), Paul Jones (CPW), Matt Malick (NPS), Patrick McCarthy (TNC), Chris Pague (TNC), Camille Richard (Lake Fork Valley Conservancy-LFVC), Jamie Robertson (TNC), John Sanderson (TNC), Tom Schreiner (CPW), Jeremy Siemers (CNHP), and Ben Stratton (USFS).

The following individuals provided valuable information and input on plant species: David Anderson (CNHP), Gay Austin (BLM), Jill Handwerk (CNHP), Lee Grunau (CNHP), Barry Johnston (USFS), Bernadette Kuhn (CNHP), Paula Lehr, Susan Panjabi (CNHP), Imtiaz Rangwala (WWA), Camille Richard (LFVC), Jamie Robertson (TNC), and Renée Rondeau (CNHP).

The following individuals provided valuable information and input on animal species: Kevin Alexander (WSC), Jim Cochran (Gunnison County), Paul Jones (CPW), Frank Kugel (UGWCD), Pat Magee (WSC), Chris Pague (TNC), Mike Phillips (CPW), Dan Reinkensmeyer (FWS), Amy Seglund (CPW), Nathan Seward (CPW), Brian St. George (BLM), Ken Stahlnecker (NPS), Jeremy Siemers (CNHP), J. Wenum (CPW), and Matt Vasquez (USFS).

We thank the Southern Rockies Landscape Conservation Collaborative (US Fish and Wildlife Service) and Wildlife Conservation Society for supporting this project. Thanks to reviewers of the final draft, including: Gay Austin (BLM), Mike Babler (TNC), Andrew Breibart (BLM), Jim Cochran (Gunnison County), Jonathan Coop (WSC), Carol Howe (USFS), Barry Johnston (USFS), Patrick McCarthy (TNC), Claudia Regan (USFS), Tom Schreiner (CPW), John Scott (NRCS), Joel Smith (Stratus Consulting), Robert Wigington (TNC), and Jim Worrall (USFS). We thank Pat Magee (WSC) for hosting the review workshops at Western State College in Gunnison. Special thanks to Jim Cochran (Gunnison County) and John Scott (NRCS) for continued support and local leadership of this project. Carrie Langford (TNC) kindly formatted this report. Finally, thanks to those who provided review and input that are inadvertently not mentioned above.

I. Introduction

Natural landscapes across the southwestern United States are changing. Rising temperatures in the region have contributed to large-scale ecological impacts, affecting a number of plants and animals (Robles and Enquist 2011). Natural resource managers and conservation practitioners need to understand impacts of climate change on land and water resources to inform land and water management decisions. This report summarizes the results of a landscape-scale climate change vulnerability assessment of 24 ecosystems (17 terrestrial and seven freshwater ecosystems) and 73 species of concern (50 plants and 23 animals) in the Upper Gunnison Basin, Colorado.

This report, developed for the Gunnison Climate Working Group, summarizes the results of a rapid landscape-scale climate vulnerability assessment for the Gunnison Basin. The primary objective of this assessment was to determine what ecosystems/habitats and species are most at risk to climate change (and why) under climate change scenarios predicted for 2050. The secondary objective was to assess the social vulnerability/resilience of ranching and recreation sectors to determine how climate change may impact local economies and human behavior. These products will inform the development of climate adaptation strategies and help natural resources managers set priorities for maintaining resilient ecosystems and species. The social resilience and vulnerability assessment project will help us understand how the social factors may interact with climate change to shape habitats, ecological processes, and the abundance and quality of ecosystem services.

This report contains a summary of climate exposure and vulnerability assessment methods and results. It is a work in progress and incorporates discussion, review and input from workshops held on May 12-13, 2011 in Gunnison, July 18, 2011 in Fort Collins, and October 26, 2011 in Gunnison, followed by further review by the Working Group and technical experts. The assessment process was designed to be relatively low cost and replicated at other landscapes, building on other ongoing related efforts (e.g., US Forest Service). It was developed by The Nature Conservancy (TNC), Colorado Natural Heritage Program (CNHP), Western Water Assessment, University of Colorado, Boulder (WWA) and University of Alaska, Fairbanks, with consultation and input by members of the Gunnison Climate Working Group (GCWG). For the detailed documentation for each of the species and ecosystems assessed, please see the Appendices.

Gunnison Climate Working Group

The Gunnison Climate Working Group (GCWG), a partnership of public land/water management agencies, academic institutions, non-governmental organizations, and landowners, is working together to: 1) increase understanding and awareness of climate change impacts on species, ecosystems, and local communities; 2) identify climate adaptation strategies; and 3) promote coordination and effective implementation of strategies. The Working Group formed shortly after the December 2009 Gunnison Climate Change Adaptation Workshop for Natural Resource Managers hosted by the Southwest Climate Change Initiative, The Nature Conservancy, and Western State College. At this workshop, participants developed a set of preliminary strategic actions for three conservation targets -- Gunnison sage-grouse, Gunnison headwaters, and alpine wetlands using the Adaptation for Conservation Targets (ACT) Framework (Cross et al. in review; Neely et al. 2010). In early 2010, the GCWG developed a team charter and work plan for building resilience in the Gunnison Basin.

One of the first steps identified by the GCWG was to conduct a rapid landscape-scale vulnerability assessment of a broader set of species of concern and ecosystems occurring in the Gunnison Basin to provide a foundation for more in-depth vulnerability assessment and adaptation planning. This assessment is intended to help land and water managers understand potential ecological effects of climate change and inform adaptation planning.

The GCWG will use this vulnerability assessment to develop landscape-scale strategic guidance for climate adaptation and resilience-building for a set of priority conservation targets and to establish on-the-ground adaptation projects in the Gunnison Basin. In addition, the Working Group has chosen to move ahead with a "no-regrets" strategy identified at the 2009 Adaptation Workshop focused on enhancing the resilience of riparian/wetland areas within the sagebrush ecosystem to build adaptive capacity of the imperiled Gunnison Sage-grouse and other wildlife species.

The GCWG is also collaborating with the Southwest Climate Change Initiative (SWCCI), a public-private partnership led by The Nature Conservancy, working to help nature and people cope with climate change using scientific knowledge and practical tools in Arizona, Colorado, New Mexico and Utah. Colorado's Gunnison Basin is one of four vulnerable landscapes within the SWCCI developing and testing ways to sustain natural resources in a changing climate (www.nmconservation.org).

Study Area

The Upper Gunnison Basin (referred to hereafter as the Gunnison Basin) encompasses approximately 3,580 square miles (approximately 2.4 million acres) and ranges from 7,500 ft. to over 14,000 ft. in elevation. The study area includes most of Gunnison County and parts of Saguache and Hinsdale Counties that drain into Blue Mesa Reservoir. Approximately 1,280,000 acres (51%) are U.S. Forest Service, about 585,000 acres (24%) are public lands administered by the Bureau of Land Management, about 40,000 acres (2%) are in the National Park System, and 160,000 acres (8%) are state, tribal, and/or municipal lands. Private lands constitute about 300,000 acres (15%) of the land (Gunnison Basin Habitat Partnership Program Committee 2011). See Figure 1.

The total population of these three counties is 23,009: Gunnison-15,394, Hinsdale-548, and Saguache-7,067 (Department of Local Affairs 2010 a and b). The majority of the Gunnison Basin is managed as public lands (Gunnison: 78%, Hinsdale: 94%, Saguache: 70%), and the National Forest Service supports about 12% of all jobs in Gunnison and Hinsdale Counties (Cheng 2006). The tri-county area has historically been dominated by traditional land-based economies (ranching, mining, forestry), but is increasingly driven by retirees and tourism. Government is a big economic factor, e.g., city, county, state, federal land agencies, particularly Western State College. While agriculture for these three counties accounts for only 10% of the jobs, it impacts 96% of private land and 89% of National Forest lands (Cheng 2007) and has the largest economic multiplier for the local economy (Tadjion and Seidl 2006). Tourism and recreation are large contributors to the greater Gunnison Basin economy (23%) and are dependent on ecosystem services such as clean water, wildlife and recreational opportunities. In addition to being current drivers of the local economy, tourism and recreation are perceived as core components of future growth (Office of Economic Development 2011 a, b & c). For the purpose of this assessment, we focused the social assessment on ranching and tourism/recreation due to their large influence on the local economy and the dependence of these livelihoods on natural resources (Knapp 2011).

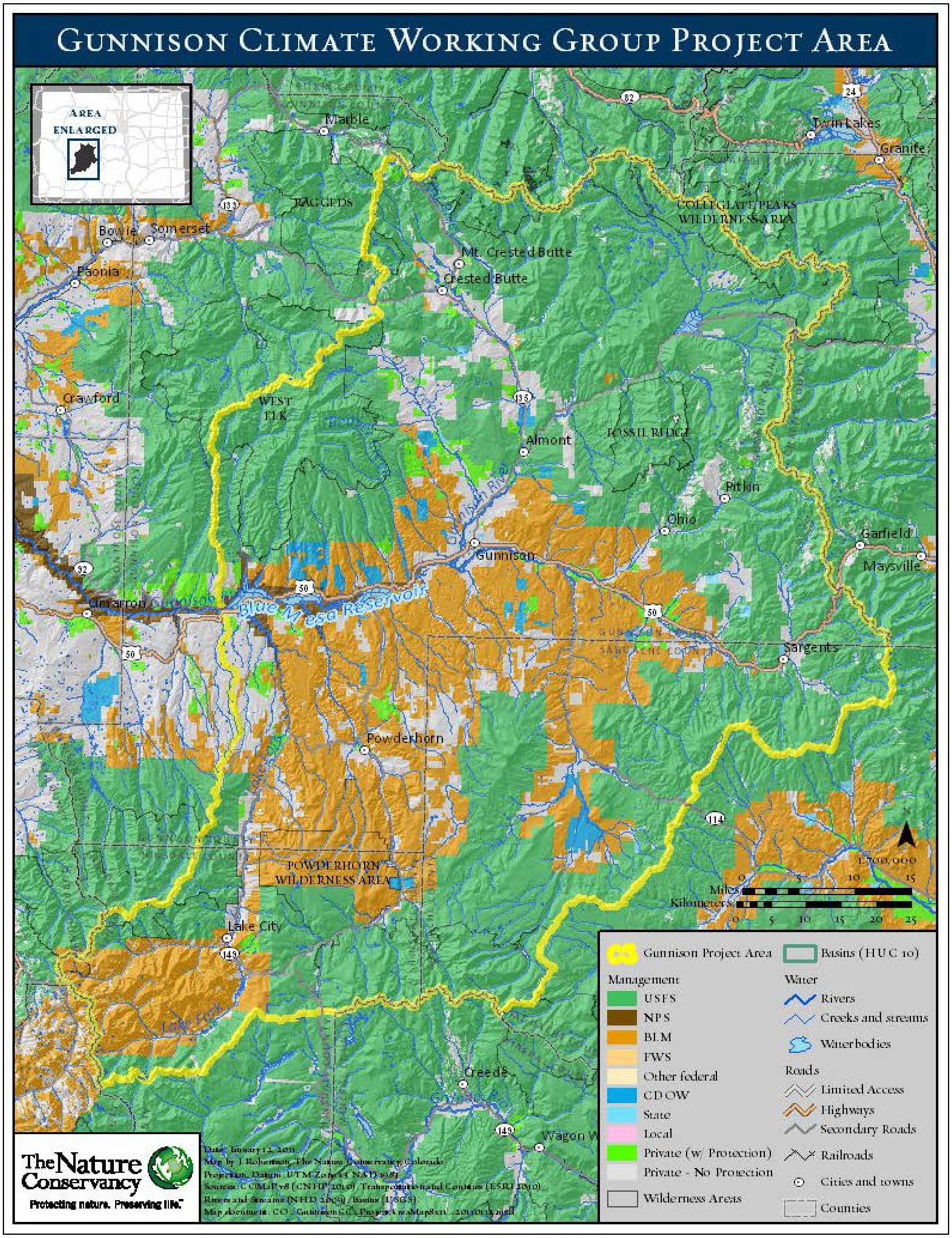

Figure 1. Map of the Gunnison Basin considered in this vulnerability assessment.

II. Methods

Vulnerability is the degree to which a system or species is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes (Glick et al. 2011). Vulnerability is a function of the character, magnitude, and rate of climate change and variation to which a system is exposed, its sensitivity, and its adaptive capacity. In this report, we focus on exposure and sensitivity to describe vulnerability. Exposure is the nature and degree to which a system or species is exposed to significant climate variations. Sensitivity is the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change (Glick et al. 2011).

For the purposes of this report, vulnerability ratings assigned to ecosystems are defined as the proportion of an ecosystem at risk of being eliminated within the Gunnison Basin as a result of climate change by 2050, e.g., highly vulnerable is defined as: the majority of an ecosystem is at risk of being eliminated (>50% loss) as a result of climate change; moderately vulnerable is defined as: the extent of the ecosystem is at risk of being moderately reduced (<50% loss). For species, extremely vulnerable is defined as: the species' abundance and/or range extent within the Basin is extremely likely to substantially decrease or disappear by 2050. Highly vulnerable is defined as: the species' abundance and/or range extent within the Basin is likely to decrease significantly by 2050. Moderately vulnerable is defined as: the species' abundance and/or range extent within the Basin is likely to decrease by 2050.

Questions

This vulnerability assessment addresses the following primary questions:

1. Which species and ecosystems are most vulnerable to predicted climate change in the Gunnison Basin and why? What factors or ecological attributes, e.g., distribution, composition, and condition, contribute to vulnerability to climate change (address to the extent possible)?
2. What is our level of confidence in our answers to the above?

Approach

The assessment team used an integrated approach based on the most applicable methods developed by the Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife (2010) for assessing the vulnerability of terrestrial and freshwater ecosystems and the NatureServe Climate Change Vulnerability Index (Young et al. 2011) for assessing plant and animal species. The team completed draft preliminary assessments of species and ecosystems between March-May, 2011. Forty-two experts, scientists and natural resource managers from academic institutions, public agencies and non-governmental organizations reviewed the preliminary climate vulnerability assessment at a workshop at Western State College in Gunnison on May 12-13, 2011. The vulnerability team then held a smaller workshop with USFS Rocky Mountain Research Station scientists and fire experts in Fort Collins on July 18, 2011 to refine the ecosystems results. Following these workshops, the writing team refined the assessment. Twenty-five participants of a GCWG workshop on October 26, 2011 provided further feedback on the assessment at a one day meeting in Gunnison. Final review of the report occurred in November-December, 2011.

The social resilience/vulnerability assessment, conducted by Corrie Knapp, University of Alaska, Fairbanks, used a document review and 36 interviews with ranchers (19), recreation business representatives (16) and one water expert to understand the resilience and vulnerability of land-based livelihoods to potential climate change and to identify adaptation strategies that may benefit both ecosystems and livelihoods (Knapp 2011). Interviews were transcribed, coded and analyzed with the qualitative data analysis software NVIVO in order to track these themes, and other characteristics of interest, across the interviews. Ms. Knapp organized the resulting coding reports into tables in order to assess themes of interest. Once preliminary results were drafted, she searched the transcripts for negative cases in order to assure that preliminary results correctly reflected the interviews.

The timeframe for this vulnerability assessment is 2040-2069 (referred to hereafter as 2050) to provide a range that most accurately describes predicted conditions for mid-century (www.climatewizard.org). This is a typical cutoff date for predictions made in Intergovernmental Panel on Climate Change reports (e.g., IPCC 2007; Young et al. 2011). Near-term projections of climate change scenarios tend to have a higher degree of certainty than those that look farther out. It is difficult to predict how greenhouse gas emissions might change in the future, whereas climate change we experience over the next few decades will be primarily caused by past emissions (Glick et al. 2011). We did not consider a longer timeframe, e.g., end-of century (2100), due to the higher level of uncertainty in long-term climate projections (Glick et al. 2011).

The assessment steps include the following:

1. Determine the climate data and models to use, and determine the list of plant species, animal species, terrestrial ecosystems and freshwater ecosystems to assess.

2. Gather and review existing reports and literature relating to climate change, ecosystems and species for the Gunnison Basin.

3. Assess climate exposure, the nature and degree to which a system or species is exposed to significant climate variations. Identify and describe historical climate patterns and projected climate change scenarios for the Gunnison Basin.

4. Assess vulnerability of plant and animal species: identify species most likely to be affected by climate change and describe factors or key ecological attributes that are most sensitive to climate change, using the NatureServe Climate Change Vulnerability Index (CCVI; Young et al. 2011).
    a. Develop criteria for species to include in the assessment and compile a comprehensive list of species of concern for the assessment (species meeting criteria but lacking sufficient information were not included).
    b. Apply the NatureServe CCVI to the set of plant and animal species.
    c. Document rationale for the species vulnerability rankings.
    d. Draft preliminary products for expert input and peer review, and incorporate comments from experts.
    e. Include confidence levels for vulnerability scores and documented data gaps.

5. Assess vulnerability of terrestrial and freshwater ecosystems: identify ecosystems most likely to be affected by climate change (based on Barsugli and Mearns 2010 projected climate scenarios) and describe factors that are most sensitive to climate change, adapting methods developed by the

Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife (MCCS and MDFW 2010).

a. Select ecosystems for evaluation from NatureServe/Colorado Natural Heritage Program and Southwest ReGAP.
b. Identify and score important factors or variables that climate change may affect. Assign overall vulnerability score based on evaluation of above factors.
c. Assess and document levels of confidence for scoring.
d. Complete vulnerability narratives with rationale for vulnerability rankings.

6. Assess social vulnerability/resilience of ranching and recreation sectors in Gunnison Basin.
   a. Document characteristics of ranchers and recreation business owners that contribute to the adaptive capacity, resilience and vulnerability of these livelihoods to climate change in the Gunnison Basin.
   b. Identify which ecosystem services (quantity/quality/timing) each livelihood is dependent upon and to document potential tipping points of concern.
   c. Identify adaptation strategies that would benefit both ecosystems and community residents.

7. Hold workshop with terrestrial and freshwater ecologists, botanists, wildlife biologists, and water and land managers to evaluate comparative vulnerabilities of the ecosystems under two climate scenarios, review scores, assign confidence scores, and identify other non-climate stressors, e.g., habitat fragmentation and invasive species, that could interact with and/or exacerbate the effects of climate change.

8. Identify the most vulnerable species and ecosystem and synthesize the results.

9. Incorporate final comments from managers/experts and finalize report for distribution.

Vulnerability Products

The specific products resulting from this vulnerability assessment include the following:

1. Description and maps of current/past and projected climate patterns for the Gunnison Basin.

2. Vulnerability assessments for plant and animal species and ecosystems of the Gunnison Basin:
   a. Species:
      - Vulnerability ranks for species with supporting documentation and references.
      - Identification of most vulnerable ecological attributes or life stage factors for each species.
      - Confidence levels assigned to vulnerability scores and narratives.

   b. Ecosystems:
      - Vulnerability ranks for ecosystems with supporting narrative evaluations.
      - Identification of factors contributing to vulnerability for each ecosystem type.
      - Confidence levels assigned to vulnerability scores and narratives.

3. Synthesis of the species and ecosystem results.
4. Social resilience and vulnerability assessment.
5. Identification of key data gaps.
6. Recommended next steps.

III. Climate Change Exposure

Climate change exposure is the nature and degree to which a system is exposed to significant climate variations (IPCC 2001; Glick et al. 2011). It is the degree, duration, and/or extent to which a system is in contact with a climate perturbation, often depicted by analysis of historic climate or climate projection data. Observations and estimates of exposure—past, present and future—serve as a foundation for assessing the vulnerability of natural features. Before we can understand or project the effects of climate change on species and ecosystems, we must understand the magnitude, frequency, extent, seasonality and duration of exposure to changes in temperature, precipitation and other biologically meaningful climate variables (McCarthy et al. 2010). The following is an overview of climate change exposure; See Appendix A for more details.

Past and Current Trends

According to the International Panel on Climate Change Fourth Assessment Report (IPCC 2007), the mean annual global temperature has unequivocally warmed over the past century, and this warming is very likely due to the accumulation of greenhouse gases, such as carbon dioxide. The observed warming has been especially rapid since the late 1970s, resulting in a decrease of the extent of Northern Hemisphere snow cover. The amount of greenhouse gases in the atmosphere will almost certainly increase in the next two decades, and, under several possible scenarios, continue to increase at a high rate, likely resulting in warming through the 21^{st} century. The overall warming in the Gunnison Basin (Figure 2) is part of a larger pattern of warming in the western United States that is likely to continue.

There have also been observed changes in the water cycle, particularly those aspects that are closely related to temperature (see Figure 3). Many areas in the West have experienced more precipitation falling as rain rather than snow, earlier snowmelt and runoff, and reductions in springtime snowpack. Several peer-reviewed studies have attributed the west-wide pattern of these hydrologic changes to greenhouse gas increases (Das et al. 2009; Bonfils et al. 2008; Pierce et al. 2008; Hidalgo et al. 2009). The situation is more complicated in the high-elevations of Colorado Rocky Mountains, including the Gunnison Basin, dominated by winter and early spring precipitation. The relatively small amount of warming that has been observed so far does not push the average wintertime temperatures above freezing, so the hydrologic cycle has not yet been strongly affected (Regonda et al. 2005).

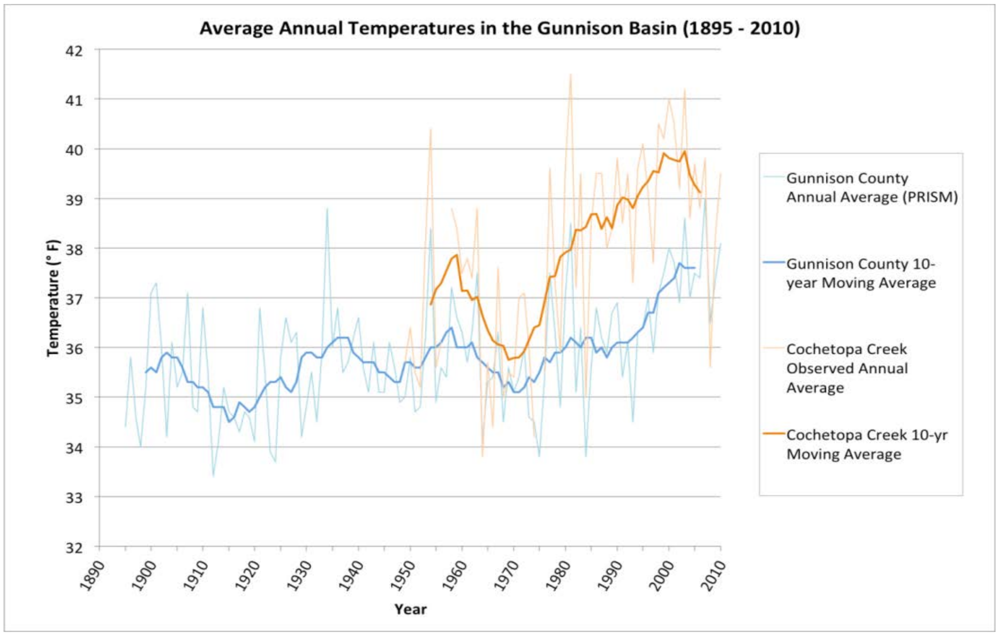

Figure 2. The Cochetopa Creek weather station (8,000 feet) and the Gunnison County average show a gradual warming from mid-century to present. While not definitive proof that the Gunnison warming will continue at the rate it has in the recent past, it makes a case that climate model projections of even greater warming should be considered as plausible futures for the Gunnison (Joseph Barsugli, Western Water Assessment, University of Colorado, Boulder). Data source: Colorado Climate Center and Western Regional Climate Center.

The Future of the Gunnison Basin

The climate of the Gunnison Basin is projected to get warmer over the next few decades as part of a larger pattern of warming in the western United States. Precipitation is projected to stay the same or increase in the winter, and to decline in the spring and summer, though precipitation projections are considerably less certain than the temperature projections. The warmer temperatures lead to earlier snowmelt and stream flow peaks, shorter snow season, and longer growing season, increased use of water by vegetation and greater loss of soil moisture in summer. Current model studies project a decline in the annual volume of stream flow.

Regional climate modeling supports the IPCC (2007) projections for the central Colorado Rocky Mountains, including the Gunnison Basin. There is a clear upward trend in temperature during the current and future time periods (1971-2000 and 2041-2070 respectively), with the mid-century being about 3°C (5.4°F) warmer than the recent past (Barsugli and Mearns 2010). For precipitation, neither period exhibits a distinct trend, but a mean decrease of 7% in precipitation from the current to the future time period is projected (Barsugli and Mearns 2010).

Despite the long-term trends, year-to-year and decade-to-decade climatic variability will still be observed in the future. That is, we do not expect a smooth upward trend in temperature with each year warmer than the previous, or a smooth upward (or downward) trend in precipitation. Climate variations will be an important factor for ecosystems and species in the future. The concern is that the long-term trends will make the warmer extremes warmer than anything observed, and the drier extremes even drier.

Changes in seasonal climate patterns add another level of complexity, and the differences between projections for winter and summer are important for the Gunnison Basin. Two global climate models were used to develop potential scenarios of how the Gunnison Basin's climate might change for the 2009 Gunnison Basin Climate Change Adaptation Workshop (Barsugli and Mearns 2010; Neely et al. 2010) and were considered in the vulnerability assessments (See Table 1). These scenarios were chosen to represent a "Moderate" and a "More Extreme" level of climate change from among the many global and regional climate model projections investigated. In both scenarios, average temperature increases during all seasons, and annual precipitation stays the same or decreases. Temperature increases most in summer, and precipitation decreases most in spring and summer. In the Moderate Scenario there is an increase in wintertime precipitation. These seasonal changes are important relative to species phenology discussed in other sections of this report and for recognizing summers to be the future periods of greatest ecological hardship.

Table 1. Two scenarios of seasonal precipitation and temperature changes from periods 1950-1999 to 2040-2060. These scenarios were developed from the range of available global and regional climate model projections for the central Colorado Rocky Mountains. The Moderate Scenario is near the median of the model projections. The More Extreme Scenario lies in the top 25% of model projections, but is not the most extreme of the climate model projections.

	Moderate Scenario			More Extreme Scenario		
Season	**Precipitation (percent)**	**Temp °F**	**Temp °C**	**Precipitation (percent)**	**Temp °F**	**Temp °C**
Annual	~0.0	+3.6 to +5.4	+2.0 to +3.0	-10.0	+5.4	+3.0
Winter	+15.0	+3.6	+2.0	~0.0	+5.4	+3.0
Spring	-12.0	+4.5	+2.5	-15.0	+5.4	+3.0
Summer	-15.0	+5.4	+3.0	-20.0	+7.0	+4.0
Fall	+4.0	+4.5	+2.5	-10.0	+5.4	+3.0

Hydrologic Changes

In addition to changes in mean annual temperature and precipitation, changes in hydrology are a major concern in the Gunnison Basin. There is no evidence for a long-term trend in the annual volume of water for the USGS stream gage on the Gunnison River near Gunnison. However, such a trend would be hard to detect against the background of year-to-year variability in the stream flow. Increasing temperatures lead to a later start of the snow season, earlier snowmelt, runoff and peak runoff, and greater evapo-transpiration from plants. Figure 3 shows average mid-21st century peak runoff in the Basin is projected to occur earlier by over a month than during the second half of the 20th century. The increase in wintertime precipitation seen in many climate model simulations can counteract some of these tendencies.

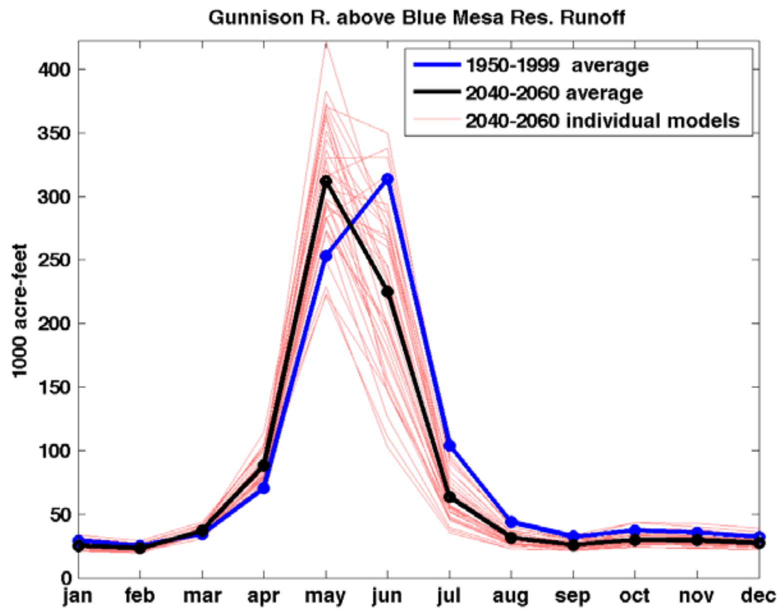

Figure 3. Projected monthly hydrograph for the Gunnison River basin above Blue Mesa Reservoir for 2040-2060 compared to the modeled average 1950-1999 hydrograph. The individual model simulations (red) show a large range of possible future flows, but they all show earlier runoff.

Snowmelt, runoff and stream flow shift earlier in the year at all elevations, but the impacts on the role of hydrology in the ecosystem can vary. The hydrology of high elevations is dominated by snowmelt. The melt season is projected to start a few weeks earlier, starting from roughly the same amount of water in the snowpack. Some features depend on groundwater flow, such as seeps, springs, and fens. The hydrologic models investigated here only calculate local soil water storage and do not explicitly calculate groundwater flows or water tables. For this vulnerability analysis, hydrologic factors, such as the level of the water table in alpine wetlands, were inferred from simple conceptual models or expert judgment.

Drought

Drought is a natural part of the climate of the Gunnison Basin, and has many definitions and dimensions. It is sometimes defined as a lack of precipitation, but other factors such as temperature and the timing of precipitation have a role in determining the severity of impacts. In the future, warmer temperatures will increase the severity of drought impacts, which would hit earlier during the spring and summer, with greater depletion of soil moisture, and therefore more stress on ecosystems. Warmer temperatures could also lead to more severe declines in summer and fall stream flow. This relationship between temperature and the severity of drought impacts has already been observed in the West (Breshears et al. 2005).

The projected seasonal shift in precipitation and runoff would also lead to greater impacts of drought in the summer. At lower elevations, summer rains are a large contributor to the total precipitation, so that the projected decline can have a proportionately larger impact. Some of the climate model simulations (e.g., the "More Extreme" scenario above) show overall decline in annual precipitation, indicating a higher risk for drought in the Gunnison Basin.

Dust-on-Snow Events

Since the mid-1800s, increasing dust-on-snow events have been another climate-related factor affecting hydrology in the Colorado Rocky Mountains, likely augmenting climate change impacts (Deems and Lucas 2011). Anthropogenic disturbances, e.g., livestock grazing, agriculture, road and site grading, and vehicles, on western aridlands loosens soils, allowing winds to carry and deposit abnormal quantities of dust onto snow-covered Colorado mountains. The dust decreases the snow's albedo – making the snow darker – so that it reflects less sunlight and absorbs more solar energy. This snow-albedo feedback results in a faster rate of snowmelt, shorter snow cover duration, earlier and potentially larger peaks in stream flow, and reduced annual runoff. Recent research in the Upper Colorado River Basin shows peak runoff to occur by an average of three weeks earlier and a 5% decrease in annual runoff during dust-loading years (Painter et al. 2010). Current hydrologic models based on climate models do not account for dust factors, and therefore are likely conservative estimates of the hydrologic impacts of climate change.

Exposure and Vulnerability

For this assessment, the team investigated an array of climate exposure data and analyses to determine historical climate trends and how the climate will likely change through the mid-21st century in the Gunnison Basin. The team decided to use the IPCC's high carbon dioxide emissions scenario (A2) because it most closely represents the current trends in emissions and global climate changes (IPCC 2007), and because adaptation strategies for plausible large changes can help prepare for smaller changes. The tool for assessing species vulnerability required temperature and precipitation data inputs from Climate Wizard (Girvetz et al. 2009), an online historic and future climate change data distribution tool, and soil moisture deficit data inputs from NatureServe (2011b). See the Species chapter below for details. The climate trends and predictions from Barsugli and Mearns (2010) informed the ecosystem assessments, along with a variety of other resources.

IV. Terrestrial Ecosystems

On the continental scale, climate is the primary determinant for the overall geographic ranges of plant species and vegetation patterns (Woodward 1987; Prentice et al. 1992; Neilson 1995). Geologic studies reveal that the geographic locations and extents of plant species have changed greatly as climate has varied in the past (Huntley and Webb 1998). Species rather than plant communities move in response to climate changes (Betancourt 2004). Numerous publications have attempted to correlate geographic patterns of vegetation and climate to predict the broad physiognomic vegetation types known as plant formations, or biomes, i.e., Koppen (1936) and Holdridge (1947). The Koppen scheme has recently been improved by Guetter and Kutzback (1990) and the Holdridge scheme by K. C. Prentice (1990). Neilson (1995) and Prentice et al. (1992) developed predictive models that had a high degree of accuracy for predicting vegetation within North America and globally. Box (1981) and Thompson et al. (2000) developed relationships between climatic parameters and distributions of important trees and shrubs that provide us with temperature, precipitation, and moisture tolerances for many of the dominant plants in North America. These parameters provide useful guidelines for assessing the potential for adapting to climate change.

Temperature, water, carbon dioxide, nutrients, and disturbance regimes are primary abiotic constraints controlling ecosystem processes and species distributions (Woodward 1987; Eamus and Jarvis 1989; Stephenson 1990; Neilson et al. 1992). Among these, site water balance is the primary determinant of terrestrial vegetation distribution in the U.S. (Woodward 1987; Stephenson 1990; Nielson et al. 1992; Nielson 1995). Site water balance is comprised of precipitation inputs balanced by water losses in the form of evapo-transpiration, runoff, and deep drainage. It is strongly influenced by temperature through its effects on evapo-transpiration, in turn modified by CO_2 concentration, which can influence vegetation water use efficiency. Areas that are quite wet or cold may be limited by available absorbed energy for growth, rather than site water balance (Nielson 1995). Stephenson (1998) found that actual evapo-transpiration and deficit (also known as potential evapo-transpiration) are biologically meaningful correlates of vegetation distribution across spatial scales.

In general, the parameters most important for predicting plant distribution are: 1) mean temperature of coldest month; 2) mean temperature of warmest month; 3) annual precipitation – although precipitation during growing season can be used; 4) growing degree days (a 5ºC base is used here); and 5) a moisture index such as actual evaporation/potential evaporation. For the most part, available moisture is the primary driving factor, followed by the coldest and warmest temperatures (Thompson et al. 2000). Growing degree days (GDD) give an estimate of how much energy is available for plant growth if moisture requirements are met. Even with sufficient energy for growth, under insufficient moisture conditions (drought), a plant will not grow and may die if the drought is severe enough.

Although we can estimate the requirements of a given species, the more difficult determinants of vegetation dynamics are the ecological processes or disturbance events, e.g., drought severity, fires, snowmelt, insect outbreaks. Because the rate of vegetation response to environmental shifts is likely to be lower than the rate of climate change itself, predictive models are limited (Prentice and Solomon 1991).

Fire is an important overarching process that can significantly shape the landscape. An upsurge in the frequency of large fires began in the mid-1980s and is expected to continue (Westerling et al. 2006; Romme et al. 2009). The predicted trend of higher fire frequency and severity has the potential to exasperate or accelerate changes to ecosystems. For warming levels of 1 to 2°C, the annual area burned by wildfire in parts of western North America is expected to increase by 200-400% for each degree (°C) of warming (National Research Council 2011). The potential for large, severe fire increases as snowpack melts earlier in the spring, leading to longer fire seasons.

Jim Worrall and Suzanne Marchetti of USFS (Gunnison office) generously provided Rehfeldt models (Rehfeldt et al. 2006, 2009) projecting impacts of climate change for aspen, spruce-fir, lodgepole pine, and Douglas-fir (maps follow the ecosystem descriptions in Appendix B). See the box below for a brief description of this modeling exercise.

Rehfeldt Models

Projecting impacts of climate change on tree species is important to determine management strategies for the future. Gerald Rehfeldt and colleagues at the US Forest Service, Rocky Mountain Research Station in Moscow, Idaho have developed a model to do just that for dozens of tree species across western North America. They developed a climate profile for each species by comparing recent climate variables (1961-1990) between areas inside and outside the current distribution of the species. Next they used three general circulation models of the IPCC to map climatic variables at a pixel size of ~1 km for 2030 (not shown), 2060, and 2090 (not shown). Finally, using the climate profile developed for each species, they estimated the probability that the projected climate in each pixel would be suitable for the species. Rehfeldt et al. made these data available online at: http://forest.moscowfsl.wsu.edu/climate/species.

We used their data to identify areas climatically suitable for tree species in the Gunnison Basin recently and in the future. For each model, we considered pixels suitable if they received ≥65% of votes from the classification tree, a measure of probability the climate will be suitable (Rehfeldt et al. 2009). We then combined the results of the three models, assigning the pixel a value 1-3, depending on how many of the three models agreed the area would be suitable. In these maps, a pixel is shown as suitable if any one of the three models indicates suitability. It is important to note that only climate is taken into account for these maps. Other variables, such as soil types and competition will limit their distribution. This is especially a factor at the highest elevations, where little soil development has occurred. These maps represent model projections and should not be regarded as precise indicators of where climate will be suitable in the future. Rather, they provide a general projection of how suitable the area is likely to change in the future as the climate changes.

Gunnison Basin Terrestrial Ecosystems

Ecosystems are dynamic assemblages or complexes of plant and/or animal communities that: 1) occur together on the landscape; 2) are tied together by similar ecological processes, underlying abiotic environmental factors or gradients; and 3) form a readily identifiable unit on the ground. For the purposes of this report, we use the term ecosystems broadly to represent ecological systems and/or vegetation types that are typically referred to as habitats. Ecosystems evaluated represent the majority of the Gunnison Basin landscape and were modified from Southwestern ReGAP (SWReGAP; Prior-Magee et al. 2007; Table 2 and Figure 4). Elevation, precipitation, and other information for each of the major ecosystems are in Appendices B-C. For terrestrial ecosystems, we assessed 13 upland and four riparian ecosystems (high, middle, and low elevation, as well as irrigated hay meadows). We included irrigated hay meadows because they are important human-managed systems not adequately captured by other riparian types and they are critically important for livelihoods of the ranching community within the Basin.

These ecosystems provide a coarser level unit than ecological types of the Gunnison Basin described in detail by Johnston et al. (2001). The classification used in this document does not have a one-to-one correlation with the ecological types described in Johnston et al. (2001), however there is overlap. Our classification is coarser and uses "ecosystems" to describe the vegetation and environment.

Note that for the purposes of this report, mesic alpine ecosystems are isolated moist meadows above treeline where snow is deposited and snowfields may remain late into the summer. They are distinguished from high-elevation wetlands described in the freshwater section that are largely subalpine, although they can extend into the alpine, and are very connected to other systems.

Table 2. Upland and riparian ecosystems evaluated (following SWReGAP; Prior-Magee et. al. 2007). No acres are available for the riparian ecosystems due to the small areas that they occupy.

Ecosystem	Acres in Study Area
Upland Ecosystem	
Xeric alpine	97,066
Mesic alpine	25,740
Spruce-fir	536,591
Douglas-fir	124,854
Aspen	196,743
Lodgepole	187,110
Ponderosa pine	30,088
Juniper woodlands	4,358
Bristlecone pine	6,614
Montane sagebrush	374,893
Low elevation sagebrush	189,991
Oak mountain shrublands	16,157
Montane grassland	125,704
Riparian Ecosystem	
High-elevation riparian	Not available
Mid-elevation riparian	Not available
Low-elevation riparian	Not available
Irrigated hay meadows	Not available

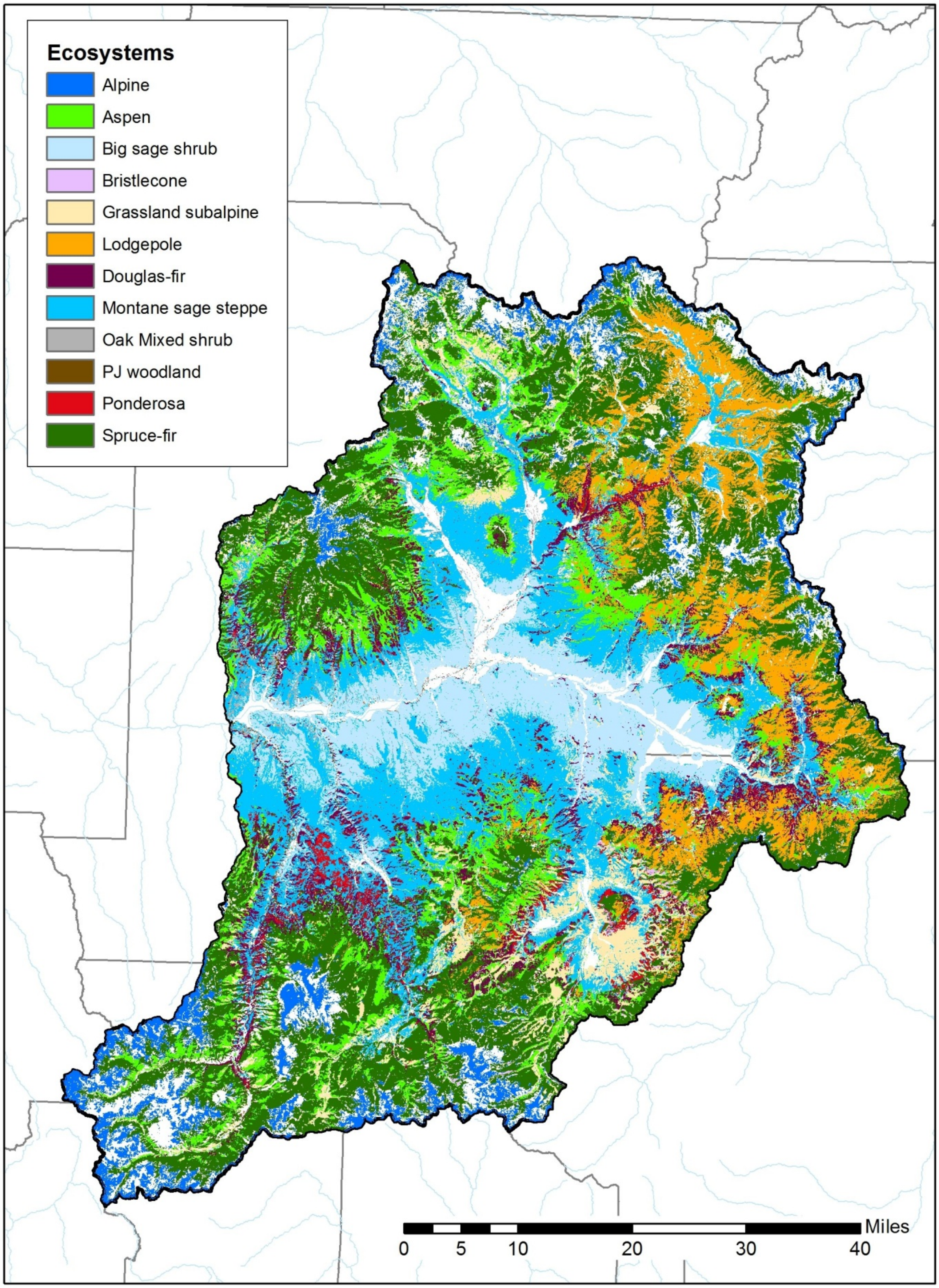

Figure 4. Major ecosystems in the Gunnison Basin, developed from SWReGap. Note that wetlands and riparian areas do not show up on this map due to the small areas that they occupy.

Approach

This section is a general appraisal of how climate change is likely to affect ecosystems within the Gunnison Basin. The list of important ecosystem factors or variables that should be considered when evaluating climate change impacts was adapted from Manomet Center for Conservation Science and Massachusetts Division of Fish and Wildlife (MCCS and MAFW 2010). An ecosystem vulnerability scoring system adapted from MCCS and MAFW was also developed (see below). This provides a framework for evaluating the comparative vulnerabilities of Gunnison ecosystems. Confidence levels were assessed using a three-point scoring system to capture the level of confidence in assigning the vulnerability score.

Our major questions were:

1. How vulnerable are terrestrial ecosystems to substantial climate change induced responses and why?

2. What degree of confidence can be assigned to the above predictions?

To answer these questions, Colorado Natural Heritage Program ecologists developed basic descriptive climatic information about the current or recent past for each ecosystem as represented in the Gunnison Basin and used Barsugli and Mearns (2010) climate scenarios for 2050 to assess the vulnerabilities. In order to compare species growing parameters we used Thompson et al. (2000) ranges (10-90%) for North America and means for Gunnison Basin ecosystems. Thompson et al. (2000) provided growing degree days calculated on a base of 5°C and a moisture index that represents Actual Evapo-transpiration as a percentage of Potential Evapo-transpiration.

Several experts were consulted (including Claudia Regan, Jim Worrall, Terri Schulz, and Barry Johnston) during the initial phase, and the May 12-13, 2011 workshop in Gunnison provided additional expert review. Finally, Linda Joyce, Claudia Regan, Mike Babler, Mary Huffman and Michael Battaglia further refined the rankings and rationale at the Fort Collins July 18, 2011 workshop.

We prepared the preliminary vulnerability analysis for each ecosystem based on knowledge of Gunnison Basin, literature review, and consultation with experts. See below for factors used in the assessment and a summary of results.

Factors likely to affect terrestrial ecosystem vulnerability to climate change in the Gunnison Basin

The team used the following factors, adapted from the MCCS and MAFW (2010) to assess each terrestrial ecosystem. We ranked the following factors for each ecosystem, and then summarized this information in an objective way to determine an overall vulnerability score, i.e., there was no algorithm used for the overall vulnerability score. See Table 3a for the scoring system for uplands and Table 3b for the scoring system for riparian ecosystems.

1. **Elevation:** What is the current elevation range in the Gunnison Basin? Identify systems that are at the extreme high elevations and assume that they are vulnerable to being reduced or eliminated by climate change (e.g., high-elevation alpine ecosystems may have no room to migrate).

2. **Bioclimatic envelope:** What are the current temperature and precipitation ranges for the ecosystem? Those systems that have a narrow range to either or both temperature and precipitation may be more

vulnerable. This includes growing degree days, which is especially important for the alpine ecosystem.

3. **Vulnerability to increased attack by biological stressors (e.g., grazers and browsers, pests, invasives, pathogens):** There are several components in this factor, including invasives, e.g., cheatgrass is a growing concern in the sagebrush ecosystems, insects, e.g., bark beetle, and root diseases that have the ability to significantly impact large coniferous stands. Higher winter temperatures and increase in droughts could increase the vulnerability to biological stressors. Ecosystems that are currently vulnerable to these stressors may become more so under climate change.

4. **Intrinsic dispersive rate:** Some plant communities may be able to shift their ranges in response to climate change more quickly than others due to, e.g., seed-dispersal capability, vegetation growth rates, or dominance by fast-growing, high reproduction potential, or stress-tolerant species. Such ecosystems (e.g., grasslands and shrublands) may be more able to adapt to shifting climatic regimes than others, such as forests. Other ecosystems may face obstacles that reduce or prevent shift in ranges in response to climate change because the obstacles prevent migration of the ecosystem upward in elevation. Such obstacles could be topographic (e.g., major water bodies, or intervening high-low elevation land), anthropogenic or geologic fragmentation, etc. Soil limitation is considered here.

5. **Vulnerability to increased frequency or intensity of extreme events (fire, drought, windstorms, and floods):** Some ecosystems may be more vulnerable than others to extreme events (fire, drought, floods, windstorms, dust on snow, etc.) that are projected to become more frequent and/or intense under climate change.

6. **Vulnerability to phenologic change:** Some ecosystems are dependent on the timing of annual events such as snowmelt, timing of run-off, etc. For example, coldwater fish ecosystem and wetlands are both influenced by the timing of spring snow-melt, ice melt, and precipitation. Changes in the timing of such events could have adverse ecosystem impacts.

7. **Likely future impacts of non-climate stressors:** Future adaptation to climate change may focus largely on enhancing ecosystems/habitat resilience. One way to address this is to minimize the effects of non-climate stressors, such as contaminants, habitat destruction, fragmentation, invasive species, pests, etc. It is important, therefore, to identify for each ecosystem which non-climate stressors may be important in the future and the comparative vulnerabilities of the ecosystems to those stressors. For example: 1) development in Gunnison is growing and could grow even more as it warms up which would increase water needs; 2) less forage (quality and quantity) could be a result of increased temperatures and droughts thereby leading to a decrease in stocking rate.

Table 3a. Ecosystem vulnerability scoring system for uplands ecosystems (adapted from Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife 2010).

Vulnerability Rating	Interpretation
Extremely Vulnerable	Ecosystem at risk of being eliminated from the Gunnison Basin as a result of climate change.
Highly Vulnerable	Majority of ecosystem at risk of being eliminated (i.e., >50% loss) as a result of climate change, but unlikely to be eradicated entirely.
Moderately Vulnerable	Extent of ecosystem at risk of being moderately reduced (<50% loss) as a result of climate change.
Presumed Stable	Extent of ecosystem approximately the same, but there are significant pattern or condition changes within the Gunnison Basin.
Slight Increase	Ecosystem may become established within the basin from areas outside.
Moderate Increase	Extent of ecosystem may expand moderately (<50% gain) as a result of climate change.
Greatly Increase	Ecosystem may expand greatly (>50% gain) as a result of climate change.
Unknown	Vulnerability of ecosystem under climate change is uncertain

Table 3b. Ecosystem vulnerability scoring system for riparian ecosystems.

Vulnerability Rating	Interpretation
Highly Vulnerable	Overall loss of system is expected to be > 50% or ecological process is expected to be severely impacted, e.g., flood frequency occurs 50% less than current flooding regime.
Moderately Vulnerable	Overall loss of system is expected to be between 10 and 50% or condition within system is expected to decline; e.g., up to 50% of riparian areas is infested by non-native species.
Low Vulnerability	0 to 10% loss of area and condition of system remains stable.

Results

Seventeen terrestrial ecosystems (13 upland and four riparian) were evaluated for their relative vulnerability to climate change in the Gunnison Basin. Ten of these ecosystems were ranked as either *highly* vulnerable (five) to climate change or *moderately* vulnerable (five).) See Tables 4-5 for a summary of these assessments by vulnerability scores and levels of confidence associated with the scoring. Confidence of these ratings ranged from high to low. In general, the ecosystems at the highest elevations were more vulnerable than ecosystems at low elevations. A plot of overall vulnerability ratings vs. confidence scores summarizes the upland results (Figure 5). See Appendix B for detailed summaries of the vulnerability assessments for each ecosystem.

Five terrestrial ecosystems – mesic alpine, xeric alpine, bristlecone pine, Douglas-fir, and low-elevation riparian – were rated highly vulnerable to climate change. The rate of vegetation change is uncertain for all ecosystems but especially for the alpine ecosystems due to the slow growth associated with the cold environment. However, predicted climatic conditions for 2050 will not likely maintain the alpine ecosystems over the long term. Mesic and xeric alpine are restricted to the highest elevations; there is low probability that alpine species will re-colonize other areas. An increase in the growing season, i.e., warmer summertime temperatures, will likely allow shrubs and trees to encroach into the alpine. Mesic alpine, consisting of small isolated patches of moist meadows, is vulnerable to drought and changes in timing of snowmelt. The bristlecone pine ecosystem is limited in distribution and, while higher habitat may become available as the climate changes, bristlecone pine recruits very slowly and may not be able to successfully colonize these areas. Moreover, this species may become more susceptible to white pine blister rust, which may increase in the future. Douglas-fir forests, occurring primarily on cold north-facing slopes, may be significantly vulnerable to warming temperatures due to increased frequency and duration of pest attacks, as well as increased fire and drought. Low-elevation riparian ecosystems, already approximately 50% converted, are vulnerable to changes in timing of snowmelt, and increased invasive species.

Five terrestrial ecosystems – spruce-fir, lodgepole pine, aspen forests, mid-elevation riparian, and irrigated hay meadows – were rated *moderately* vulnerable. Spruce beetle, western balsam bark beetle, and root diseases, along with predicted increase in fire, are likely to cause substantial additional mortality in spruce-fir forest under a warmer climate with drier growing seasons (Jim Worrall, USFS, pers. communication). Lower elevation spruce-fir may be most vulnerable. In lodgepole pine forests, drought and warmer temperatures may increase fire frequency and severity of stand-replacing fire and lethal insect outbreaks by mountain pine beetle. In the past, much of the Basin's high-elevation lodgepole pine was considered too cool for mountain pine beetle to consistently complete its life cycle in a year. Warmer temperatures and longer growing seasons may change that, independent of drought. Aspen is particularly sensitive to drought; long-term droughts may reduce the size and/or impair the ecological functioning of aspen stands, especially at lower elevations. Mid-elevation riparian ecosystems and irrigated hay meadows are vulnerable to changes in timing of snowmelt, increased invasives, decreased base flows and drought.

Four ecosystems were rated *low* vulnerability or *presumed stable* to *moderate increase* – juniper woodlands, low-elevation sagebrush, montane grassland, and high-elevation riparian. The first three ecosystems occur primarily at the lower elevations and although any given current patch may succumb to climate change, the overall ecosystem is predicted to move into nearby and unoccupied areas, that is, they will have the ability to migrate and adapt. Grasslands and shrublands are more tolerant to dry and hot conditions than forests, and are likely to invade areas where forests are lost. Although currently poorly represented in the Gunnison Basin, juniper may expand into adjacent sagebrush systems with climate change. Future expansion will likely be determined by winter precipitation patterns, and pinyon may be able to return to the area, with a resulting expansion of these woodlands into adjacent sagebrush shrublands. High-elevation riparian ecosystems, rated presumed stable, restricted to higher elevations, may be vulnerable to invasive species and increased grazing/browsing.

Low-elevation sagebrush shrublands are not expected to be limited by a requirement for cooler, high-elevation habitat. Stands in the Gunnison Basin are already established in cooler, drier habitats than are typical for this type outside the area. There are no apparent barriers to dispersal for these plant communities, although there is some question of whether adjacent juniper communities will replace the big sagebrush stands if winter temperatures warm sufficiently. While individual stands of sagebrush are vulnerable to increased invasive species, e.g., cheatgrass, and increased frequency/severity of fires, sagebrush will likely migrate into adjacent elevations with appropriate moisture and environmental conditions. While the team assumed there would be open habitat for sagebrush to move into, complications include differences in lag time of movement of forested types, soil texture and competition (Claudia Regan, USFS, pers. communication). Grasslands are also expected to increase under hotter and drier conditions. Some species, such as shrubs and grasses that can cope with drier conditions, will likely be winners while other species, such as trees, may be losers as climate change progresses due to moisture stress.

Three ecosystems – ponderosa pine, montane sagebrush, and oak mountain shrubland – were rated *moderate increase*, meaning that conditions may be more favorable for these ecosystems in the future compared to the recent past. While individual stands of sagebrush may be set back by drought or warmer temperatures, sagebrush has the ability to expand into adjacent areas that are currently forested, such as aspen or alpine if upper elevations become warmer and drier (assuming appropriate environmental conditions, as discussed above).

Please note that there were differing opinions regarding the relative vulnerability of several ecosystems, particularly sagebrush, aspen forests, and Douglas-fir forests. The vulnerability ratings for these and other species should be updated as new information becomes available.

Table 4. Vulnerability and confidence scores for terrestrial ecosystems in the Gunnison Basin.

Ecosystem	Vulnerability Score	Current Condition	Confidence in Score
Uplands			
Xeric alpine	Highly vulnerable	Good	High
Mesic alpine	Highly vulnerable	Good	High
Spruce-fir	Moderately vulnerable	Good	Low
Douglas-fir	Highly vulnerable	Fair	Low
Aspen	Moderately vulnerable	Fair to Good	Low
Bristlecone pine	Highly vulnerable	Good	Low
Lodgepole pine	Moderately vulnerable	Good	Medium
Ponderosa pine	Moderate Increase	Good	Low
Juniper woodlands	Presumed Stable to Moderate Increase	Good	Medium
Montane sagebrush	Moderate Increase	Good	Medium
Low-elevation sagebrush	Presumed Stable	Fair to Good	Low
Oak mountain shrubland	Presumed Stable	Fair to Good	Medium
Montane grassland	Presumed Stable	Good	Low
Riparian			
High-elevation riparian	Low to Moderately vulnerable	Good	Medium
Mid-elevation riparian	Moderately vulnerable	Good	Medium

Ecosystem	Vulnerability Score	Current Condition	Confidence in Score
Low-elevation riparian	Highly vulnerable	Fair	Low
Irrigated hay meadow	Moderately vulnerable	Good	Medium

Current Condition Definitions for Uplands and Riparian Ecosystems:
Very good – system can maintain itself, ecologically functioning and desired condition
Good – Desired condition, needs management to be maintained
Fair – Degraded condition
Poor – Very degraded condition, will be lost if action is not taken soon

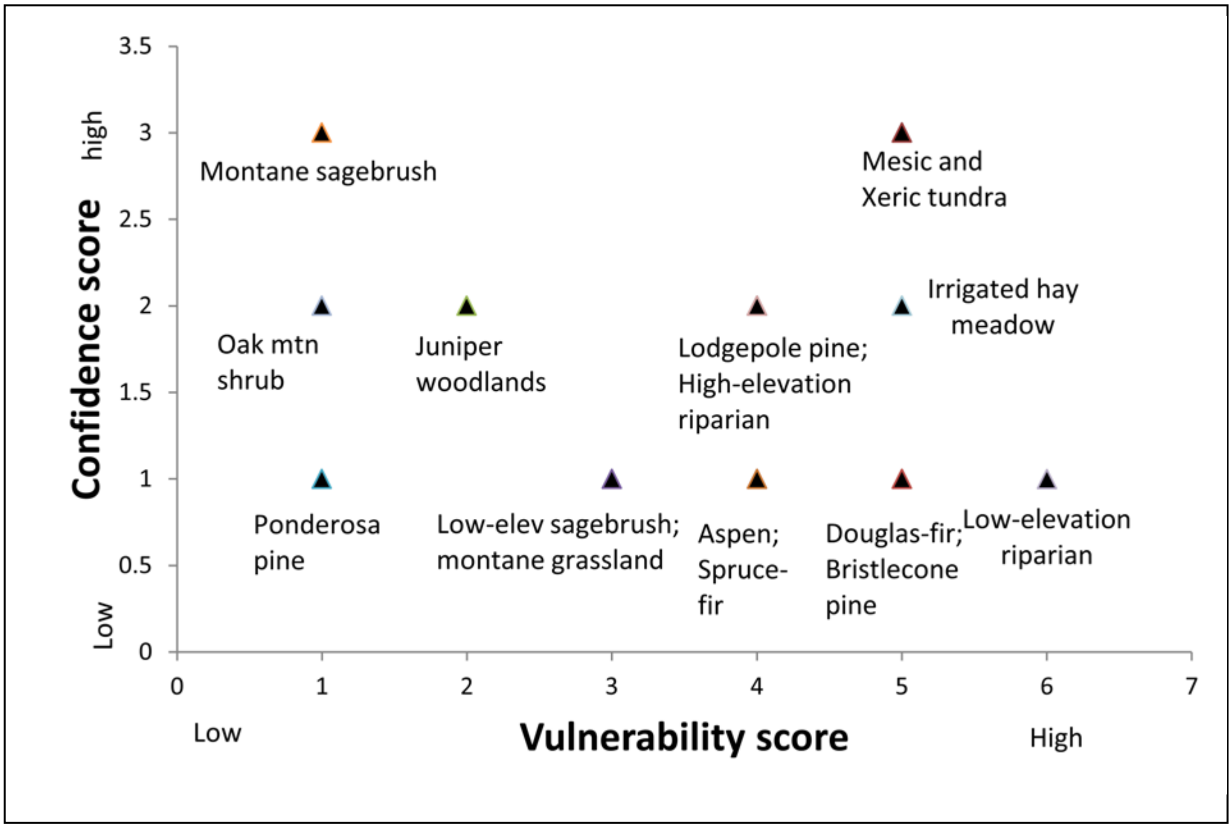

Figure 5. Vulnerability and confidence scores for terrestrial ecosystems in the Gunnison Basin. The vulnerability scores range from low to high with the lowest scores equal to a likely increase (least vulnerable) and the highest scores equal to the most vulnerable (see above table for definitions). The confidence score represents our confidence in the overall vulnerability score.

Table 5. The factors contributing to each ecosystem's relative vulnerability in the Gunnison Basin:
High: critical factor for identifying the reaction of this system to expected climate change (does not imply a shift to another ecosystem type)
Medium: moderate factor for identifying the reaction of this system to expected climate change
Low: some effect, but not a major factor for identifying the reaction of this system to expected climate change
-: not an important factor

Upland Terrestrial Ecosystems

Vulnerability											
Ecosystem	**Vulnerability Score**	**Restricted to high elevation/ or at southern edge of range**	**Narrow bioclimatic envelope**	**Increased pest attacks**	**Increased invasive species and encroach ment from natives**	**Barriers to intrinsic dispersal ability**	**Fire**	**Drought**	**Timing of snowmelt**	**Phenologic change**	**Increased grazing or browsing**
Xeric alpine	Highly Vulnerable	**High**	**Medium**	-	**Medium**	**High**	-	-	-	**Medium**	**Low**
Mesic alpine	Highly Vulnerable	**High**	**Medium**	-	**Medium**	**High**	-	**Low**	**Medium**	**Medium**	**Low**
Spruce-fir	Moderately Vulnerable	-	-	**High**	**Low?**	-	**Medium**	**Medium**	**Medium**	-	-
Douglas-fir	Highly Vulnerable	-	Medium	**High**	-	-	**High**	**High**	High	-	**Medium**
Aspen	Moderately Vulnerable	-	**Low**	**Medium**	**Low**	**Medium**	**Low**	**Medium**	**Low**	**Low**	**High**
Bristlecone pine	Highly Vulnerable		**Low**	**High**	**High**	**High**	**Low**	-	**Low**	-	-
Lodgepole	Moderately Vulnerable	**Low**	**Low**	**High**	**Low**	-	**High**	**Medium**	-	-	-
Ponderosa pine	Moderate Increase	-	-	**Low**	**Medium**	-	**Low**	**Low**	-	-	**Low-Med**
Juniper woodlands	Presumed Stable to Moderate Increase	-	-	**Low**	**Low**	**Low**	**Low**	**Low**	-	-	-
Montane sagebrush	Moderate Increase	-	-	-	**Medium**	-	**Low**	**Low**	-	-	**Low**

Ecosystem	Vulnerability Score	Restricted to high elevation/ or at southern edge of range	Narrow bioclimatic envelope	Increased pest attacks	Increased invasive species and encroach ment from natives	Barriers to intrinsic dispersal ability	Fire	Drought	Timing of snowmelt	Phenologic change	Increased grazing or browsing
Low elevation sagebrush	Presumed Stable to Moderate Increase	-	**Low**	-	**High**	-	**High**	**Low**	**Low**	**Low?**	**Low**
Oak mountain shrubland	Presumed Stable	-	**Low**	**Low**	**Medium**	-	-	**Low**	-	**Low**	**High**
Montane grassland	Presumed Stable	-	**Low**	**Low**	**Medium**	**Low**	**Low**	**Low**	-	**Low**	**Medium**

Riparian Ecosystems: Note the factors used to rate the vulnerability of riparian ecosystems are based on factors used to evaluate both the upland ecosystems and the freshwater ecosystems.

Vulnerability												
Ecosystem	**Vulnerability Score**	**Restricted to High Elevation/or edge of southern range**	**Increased pest attacks**	**Increased invasive species and encroachments from natives**	**Dispersal rate**	**Fire**	**Drought**	**Timing of snowmelt**	**Phenologic change**	**Increased grazing/ browsing**	**Current loss and stress**	**Decrease in base flows**
High-elevation	Low to Moderately Vulnerable	**High**	**Low**	**Medium**	**Low**	**Low**	**Low**	**Low**	**Low**	**Medium**	**Low**	**Low**
Mid-elevation	Moderately Vulnerable	**Low**	**Low**	**Medium**	**Low**	**Low**	**Medium**	**Medium**	**Low**	**Medium**	**Medium**	**Medium**
Low-elevation	Highly Vulnerable	**Low**	**Medium**	**High**	**Low**	**Medium**	**Medium**	**High**	**Medium**	**Medium**	**High**	**Medium**
Irrigated hay meadow	Moderately Vulnerable	**Low**	**Medium**	**Medium**	**Low**	**Low**	**Medium**	**High**	**Low**	**Medium**	**Low**	**High**

V. Freshwater Ecosystems

Introduction

Semi-arid areas such as western Colorado are particularly vulnerable to the impacts of climate change on freshwater resources (Kundzewicz et al. 2007). The effects of climate change could be particularly profound for freshwater ecosystems of the Rocky Mountains and their component species because those systems are strongly dependent on temperature and stream flow regimes that are already documented to be changing (Rieman and Isaak 2010). This assessment of freshwater ecosystems is part of a climate vulnerability assessment for the Upper Gunnison Basin. The intent was to determine what ecological systems are most at risk to climate change (and why) under climate change scenarios predicted for 2050 (Barsugli and Mearns 2010). Assessment products will inform the development of adaptation strategies and help managers set priorities for maintaining resilient ecosystems and species. This section on freshwater ecosystems follows the approach used for terrestrial systems (note that vulnerability ratings for freshwater systems considered changes in condition more important than the terrestrial systems, which emphasized spatial extent).

Freshwater Ecosystem Responses to Climate Change

Ultimately, climate is the primary determinant for the overall geographic ranges of plant species and vegetation patterns (Woodward 1987; Prentice et al. 1992; Neilson 1995). However, for rivers and streams, riparian areas, wetlands, and lakes, local site factors are the major proximate influence on ecosystem function. Site hydrology, geomorphic setting, and, for lotic ecosystems, disturbance are major factors governing species composition.

Predicted warming air temperatures and changing precipitation translate to increasing air and water temperatures; alteration of hydrology; and changes in the frequency, magnitude, and extent of extreme events such as floods, droughts, and wildfires (Hamlet and Lettenmaier 2007; Howe et al. 2011; Ray et al. 2008). Kittel et al. (2011) described general ways in which the physical aspects of freshwater ecosystems may change:

- For river environments, responses may include increased air and water temperatures, altered seasonal hydrograph (e.g., earlier peak flows and longer periods with low summer flow), increased flooding, shorter river-ice period, increased sedimentation, and changes in channel structure.

- For lake and reservoir habitats, responses may include warmer air and water temperatures, shorter ice-covered period, altered vertical thermal structure (e.g., thermocline depth and gradient) with consequences for nutrient cycling, and shifted shoreline environments.

- For wetlands, responses may include warmer air and water temperatures, reduced wetland size and depth, and loss of seasonal wetland habitat.

These responses to physical aspects of freshwater ecosystems may then be followed by biological responses. Vulnerability to climate change of the species, populations, and communities that make up freshwater ecosystems will depend on a context defined by the characteristics of those species and local environments, past habitat disruption, fragmentation and loss, and the nature of the change that occurs (Rieman and Isaak 2010). For example, trout have known sensitivities to temperature (Wenger et al. 2011) but may also be sensitive to increased sediment deposition in the river environment (Lawler et al. 2010). Or, historic loss and habitat degradation in low-elevation springs and wetlands (Doyle 2003) may put Gunnison Sage-grouse at risk of having less brood-rearing habitat or habitat of a poorer quality as increased temperatures reduce the size and number of these habitats. Biotic interactions are increasingly recognized as important components of climate-species relationships (Wiens et al. 2009; Van der Putten et al. 2010). For example, climate-induced changes in non-native trout species may affect already marginalized native cutthroat species (Wenger et al. 2011).

Gunnison Basin Freshwater Ecosystems

The presence of surface water or near-surface groundwater sets freshwater ecosystems apart from terrestrial systems by creating small- to medium-scale conditions that strongly govern ecological processes and outcomes at a site. Numerous classification schemes exist for streams, wetlands, lakes, and riparian areas. For this project, we used concepts underlying existing schemes to inform our classification of systems, but we did not use any classification in its entirety. Rather, we developed an *ad hoc* classification that combined hydrologic processes, size, elevation (a surrogate for temperature), and biological composition in a manner that accounts for on-the-ground analysis and management units.

Seven freshwater ecosystems were defined for the Upper Gunnison Basin. These are defined by size, elevation, and hydrologic function. In developing this classification, we focused on definitions that make intuitive sense and can be understood in a management context. Also, rather than focusing on habitats (e.g., aquatic habitats for fish, riparian habitats consisting of willows and sedges), we took a broad approach to ecosystems, defining them to include all ecosystem components that are governed by hydro-geomorphic setting. For example, we considered stream ecosystems as consisting of both in-channel habitats and the closely-linked riparian vegetation.

The freshwater ecosystems we assessed (Table 6) are more fully characterized in Appendix D. Figure 6 shows locations of stream and river systems, as well as the large reservoirs. Lakes and wetlands are not shown on Figure 6 because they are small features that do not show up at the whole-watershed scale, but elevation bands indicating where these features can be expected are shown. The high-elevation wetlands described in this section occur above 9,000 feet primarily in the subalpine zone, although they can extend into the alpine zone. Unlike the mesic alpine ecosystem (see terrestrial section), they are highly connected to other systems. Mesic alpine ecosystems are isolated moist meadows above treeline where snow is deposited and snowfields may remain late into the summer.

Table 6. Upper Gunnison Basin Freshwater Ecosystems

High-elevation small streams
Mid-size streams
Rivers
High-elevation, groundwater-dependent wetlands
Montane groundwater dependent wetlands
High-elevation lakes
Reservoirs and associated wetlands

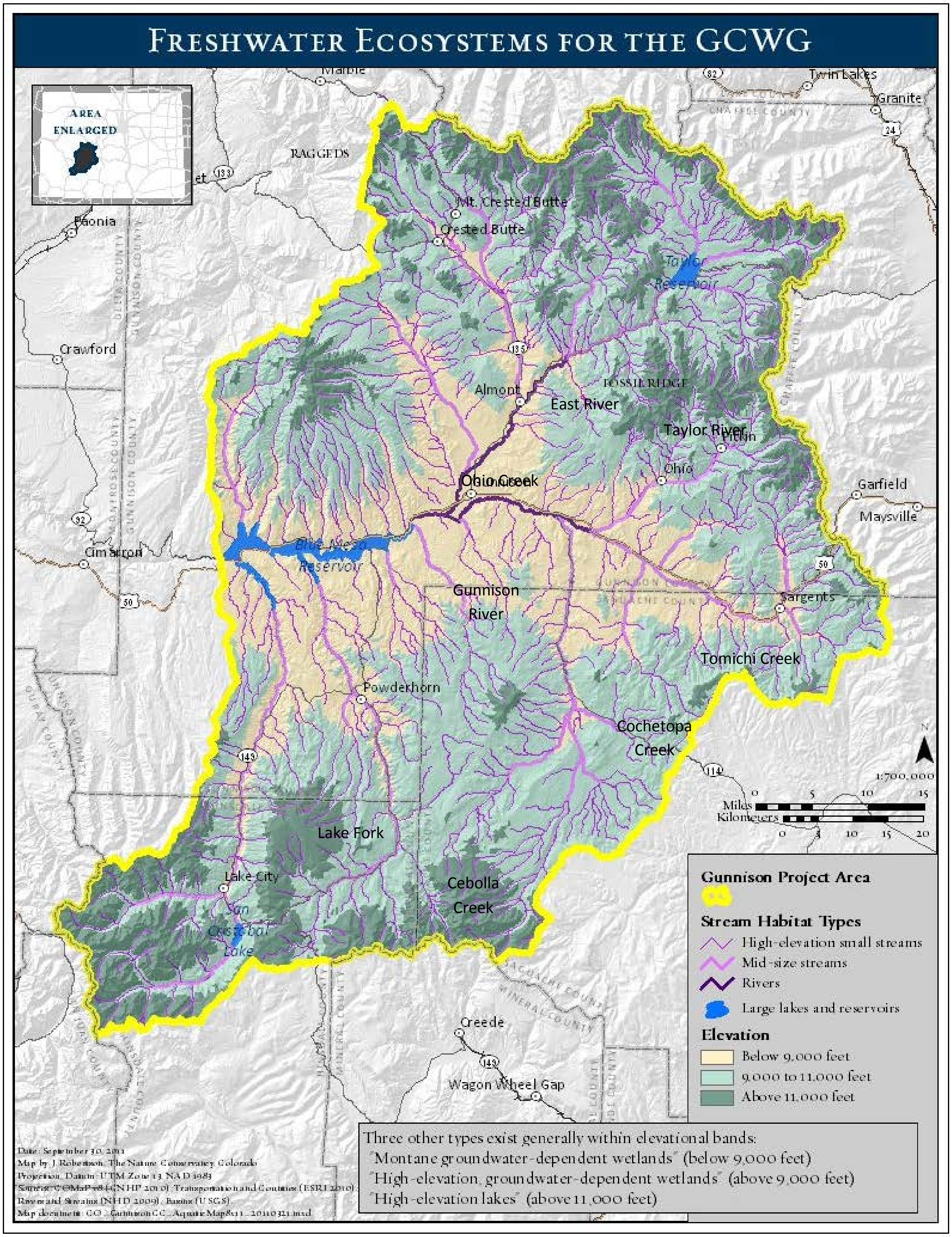

Figure 6. Freshwater ecosystems of the Upper Gunnison Basin.

Approach

Our major questions were:

1. How vulnerable are freshwater ecosystems to substantial climate change-induced responses in the Gunnison Basin and why?

2. What degree of confidence can be assigned to the above predictions?

Answers to these questions emerged from a multi-step process:

1. *Identify the factors contributing to each ecosystem's comparative vulnerability.* The list of factors used by the Manomet Center for Conservation Science and Massachusetts Division of Fish and Wildlife (2010) provided a starting point, and were modified to fit the Upper Gunnison Basin during the May 2011 workshop.

2. *Assign a rating of high, medium, or low to each factor for each ecosystem to indicate vulnerability to that factor.* This approach also followed the Manomet method, but with only three rating levels for both factors and overall vulnerability, because we felt we had insufficient knowledge of climate effects to be more precise. Ratings were assigned during the May 2011 workshop and were based primarily upon expert knowledge of freshwater ecosystems in the Gunnison Basin. After the workshop, the primary authors of this report added specific examples of possible effects on similar ecosystems reported in the literature. The panel of experts in Gunnison assigned a confidence score (high, medium, or low) to their rating of vulnerability to each factor.

3. *Estimate overall vulnerability for each ecosystem, and confidence in our estimate of that vulnerability*. A quantitative estimate was calculated by assigning a numeric value (3, 2, 1) to vulnerability estimates (high, medium, and low, respectively), then calculating the average of these values. A similar estimate was made for the overall confidence in the rating.

Factors likely to affect freshwater ecosystem vulnerability to climate change in the Gunnison Basin

1. **Current loss / stressors.** Ecological systems that have undergone substantial losses or experience substantial impacts from human activities can be expected to be more vulnerable to future changes, all other factors equal. Existing integrity of stream channels, riparian habitats, and floodplains may moderate or exacerbate negative effects of climate (Haak et al. 2010). Barriers that inhibit movement such as agricultural diversions are common throughout the upper Gunnison region. This limits the ability of fish to move to more suitable habitat as climate changes. Diversions for agricultural and municipal supply that deplete streamflows reduce total available habitat, change the timing and amount of streamflow, and fragment streams. Roads and agricultural land use can increase sediment supplies and nutrients to streams. Depleted streams are more susceptible to impacts from ambient temperature and other water quality. Land use can directly affect riparian areas, particularly where native plants are removed, or where heavy grazing occurs. Changes in vegetation cover to due land use, heavy grazing, or other factors can lead to excessive erosion. Non-native species are present throughout the Gunnison Basin, and in some instances their presence has a strong influence of native species and ecosystem function. However, in the case of non-native sport fishes, i.e., brook trout

(*Salvelinus fontinalis)*, brown trout (*Salmo trutta)*, rainbow trout (*Oncorhynchus mykiss)*, and kokanee (*Oncorhynchus nerka*), their presence is highly desirable in portions of the Upper Gunnison. Several grasses that are not native to Colorado, e.g., timothy (*Phleum pratense)*, Kentucky bluegrass (*Poa pratensis)*, and smooth brome (*Bromus inermis)*, also have major impacts on the composition of native riparian and wetland ecosystems, while also being viewed favorably for some purposes such as hay production. The beaver (*Castor canadensis*) is a keystone species that create suitable habitat for other species and their ponds may buffer these species against climatic extremes. Loss of beaver therefore has effects for other animals and plants.

2. **Vulnerability to increasing temperature**. Increased temperature can have both direct and indirect effects on species and ecosystems. This factor is intended to address only direct effects of higher temperatures, rather than indirect effects such as an earlier snowmelt peak, addressed elsewhere. Effects of temperature increases already have been documented for some aspects of ecosystems in the Upper Gunnison (e.g., flowering plants; Inouye 2008). The most obvious potential impact of increasing air temperatures is that it will lead to increased stream temperatures, potentially causing stream temperatures to approach the thermal limits of native fish, particularly salmonids (Haak et al. 2010; Mote et al. 2003). Increasing temperatures can also result in changes in the timing of flowering and seeding of cottonwood and willow (Merritt and Wohl 2002) as well as emergence of aquatic insects (Harper and Peckarsky 2006; Shafroth and Beauchamp 2006). Higher temperatures may also increase productivity of algae, plants, invertebrates, and fish.

3. **Vulnerability to pathogens**. Negative impacts resulting from whirling disease, giardia, cryptosporidium, and possibly other pathogens could increase. Indirectly, the loss of conifer forest from mountain pine beetle (see terrestrial ecosystems section above) can alter how much water reaches the stream and when.

4. **Vulnerability to increased damage from invasive species**. Increased temperatures and hydrologic changes that result from these increases may make freshwater and riparian ecosystems more susceptible to invasion by non-native species. Of particular concern are quagga mussel, New Zealand mudsnail, rusty crayfish, and Eurasian millefoil, but unforeseen invasives are also possible. Didymo, a native alga that can have highly adverse impacts when its population explodes, could experience climate-change induced spread and increase if streams experience longer periods without floods (Miller et al. 2009).

5. **Restricted to specific hydro-geomorphic setting**. Fundamental geomorphic characteristics that define stream and wetland systems (elevation, slope, drainage area) do not change appreciably over decades. In this respect, headwaters are constrained by upper limits to watersheds, several medium and large streams are constrained at their lower limits by the presence of water bodies, including large reservoirs, and springs and wetlands are fixed in location. However, in some cases changes in hydrology and water quality characteristics (particularly temperature) could effectively transition one systems type to another.

6. **Vulnerability to extreme events.** Changes in the frequency of floods and drought could affect geomorphic processes (affecting the structure of instream and riparian habitats; Poff 1992), sedimentation, water quality, and the ability of small populations to persist. Narrowleaf cottonwood

asexual reproduction could be greater with more frequent large floods. Sediment flows after major fires can severely impact instream habitat availability and quality, but sediment can also be moved out quickly with additional high flows. Without flushing, excessive sediment can be expected to adversely impact individual streams, but this effect may not be widespread. An increase in intense isolated monsoon storms can result in debris flow and mudslides, impacting aquatic habitat in smaller streams (Andrew Breibart, pers. communication).

7. **Dependence on snowmelt magnitude and timing**. Species that are highly dependent on the timing and magnitude of snowmelt, as well as the shape of the snowmelt hydrography, could be affected by the anticipated earlier peak flow, potentially infrequent but larger floods, shorter duration of the flood period, and steeper ascending and descending limbs of the hydrograph. Patterns of cottonwood (and willow) establishment from seed could change, ultimately affecting the abundance and distribution of these species. Timing of spawning may shift. Flooding due to earlier and/or rapid runoff can result in scouring out of aquatic habitats, resulting in loss of vegetation and other habitat features, as well as flushing resident trout or eggs out of the most suitable habitats (Howe et al. 2011). Geomorphological processes may be affected, with resulting changes in riparian and aquatic habitat, including changes in the size and distribution of pools, structural diversity, and channel width.

8. **Vulnerability to decreasing baseflows**. Higher temperatures and changes in the timing of snowmelt runoff are expected to result in lower baseflows. There may also be less groundwater discharge to springs, wetlands, and small streams. Lower baseflows and groundwater discharge: a) reduces aquatic, spring, and wetland habitat area; b) make temperatures of aquatic habitats more responsive to changes in ambient temperatures; and c) less water makes lotic systems more vulnerable to water quality impacts. Decreased discharge and lower stream depth during summer may increase exposure of benthic communities to ultra-violet radiation, which can substantially reduce invertebrate productivity (Clements et al. 2008). Also, decreasing water supply puts human water supply more at-risk, potentially increasing the need for even more dams and diversions from streams and rivers.

9. **Likely future impacts of non-climate stressors (including human response to climate change).** Decreasing water runoff resulting from climate change could trigger people to build new reservoirs, new diversions for human used (cities and ranches), and higher agricultural water use (as evapotranspiration increases) as we attempt to buffer our water supplies from climate change and population growth. Impacts of cloud seeding intended to induce more precipitation are unknown. As human populations increase, there may be new roads and trails. Also, point and non-point pollution discharges may increase from mines and human settlements.

Results

Vulnerability of the seven freshwater ecosystems assessed ranged from *low to moderate* to *high* (Tables 7-8), whereas confidence in these ratings was medium to high in all cases. Relative overall vulnerability ratings clustered into three groups (Figure 7).

Only one ecosystem – montane groundwater-dependent wetlands – was rated *high* for vulnerability. These wetlands include primarily seeps and springs below 9,000 feet. Six of the nine vulnerability factors were ranked high, and high confidence was given for all of these ratings. These wetlands are already in poor condition due to water development, grazing, and non-native invasive species, and it is expected that this poor condition will be exacerbated by climate change.

At the other end of the spectrum, high-elevation ecosystems were ranked *low to moderate* for vulnerability (Tables 7-8). These low ranks resulted from these ecosystems being: currently in good condition; mostly on public lands and thereby offered a high level of protection and management; base flows will change minimally at these elevations (Markstrom et al. *in press*); and that despite higher temperatures these ecosystems are expected to remain cold and thereby resistant to pathogens and invasive species. The only factor rated 'high' for these ecosystems was 'restricted to specific hydro-geomorphic setting', applicable to lakes and wetlands, but not streams. Although most factors point to low vulnerability, vulnerability could be higher based on work in arctic lakes that suggests that a longer growing season and warmer temperatures could result in large changes in algal and invertebrate communities (Smol et al. 2005).

The three ecosystems rated *moderate to high* for vulnerability all had the lowest confidence in the ratings (Table 7-8). These ecosystems all had at least two 'high' vulnerability factors, and four or more factors with a 'medium' rating, although the factors with these ratings varied by ecosystems. The medium confidence in the overall ratings for these ecosystems appears to have resulted from the size and complexity of these ecosystems, such that it projected ecosystem response was not clear.

Table 7. Vulnerability and confidence scores for freshwater ecosystems in the Gunnison Basin.

Habitat	Vulnerability Rating	Current Condition	Confidence in Score
Small high-elevation streams	Low to Moderately Vulnerable	Good	High
Mid-size streams	Moderate to Highly Vulnerable	Good	Medium
Rivers	Moderate to Highly Vulnerable	Good	Medium
High-elevation, groundwater-dependent wetlands	Low to Moderately Vulnerable	Fair	High
Montane groundwater-dependent wetlands	Highly Vulnerable	Poor	High
High-elevation lakes	Low to Moderately Vulnerable	Good	High
Reservoirs and associated wetlands	Moderately Vulnerable	Fair	Medium

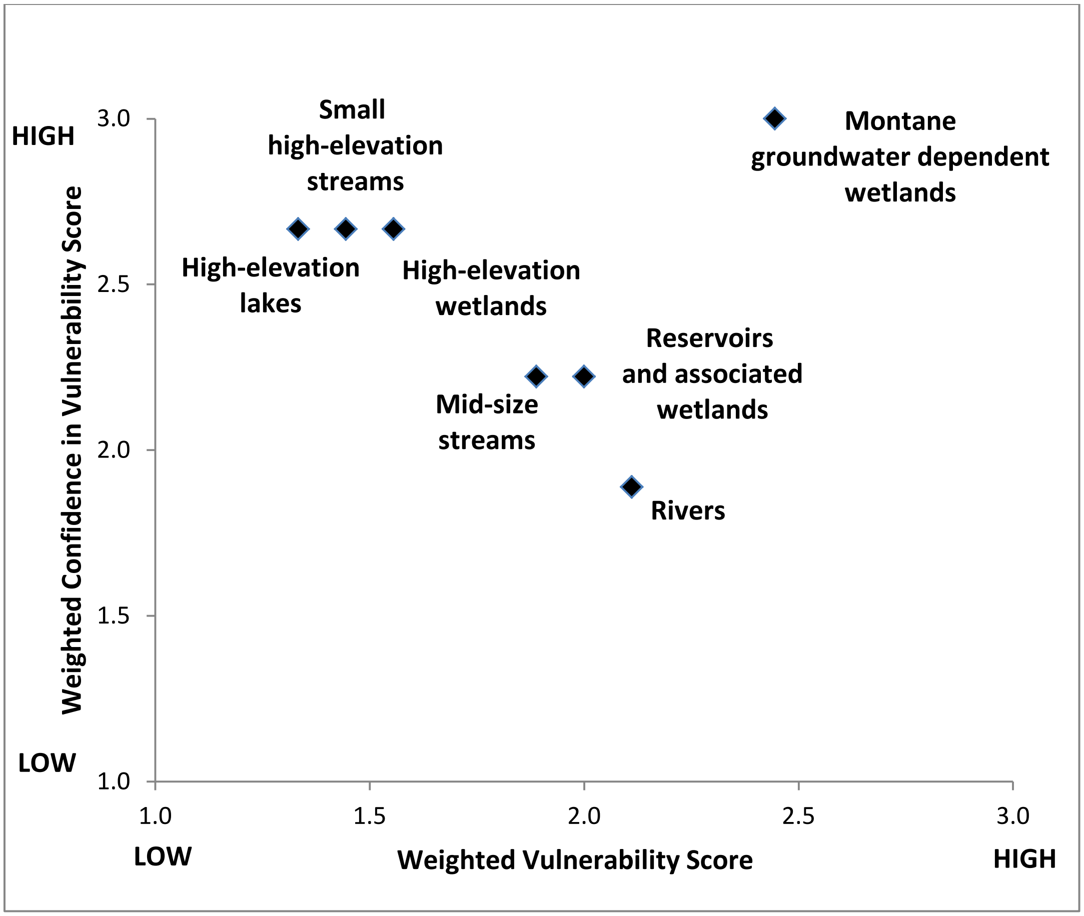

Figure 7. Relative distribution of weighted vulnerability and confidence scores for freshwater ecosystems.

Table 8. The factors contributing to each freshwater ecosystem's relative vulnerability and the confidence in those ratings.

(a)

VULNERABILITY	Current loss / stressors	Vulnerability to increasing temperature	Vulnerability to pathogens	Vulnerability to invasive species	Restricted to specific hydro-geomorphic setting	Vulnerability to extreme events	Dependence on timing and magnitude of snowmelt	Vulnerability to decreasing baseflows	Likely future impacts of non-climate stressors
Small high-elevation streams	Low	Low	Low	Low	Medium	Medium	Medium	Medium	Low
Mid-size streams	Low	Medium	Medium	Low	Low	Medium	High	High	Medium
Rivers	Low	Medium	Medium	Medium	Medium	Medium	High	High	Medium
High-elevation groundwater-dependent wetlands	Medium	Medium	Low	Low	High	Low	Low	Medium	Low
Montane groundwater-dependent wetlands	High	High	Medium	High	High	Low	Low	High	High
High-elevation lakes	Low	Low	Low	Low	High	Low	Low	Medium	Low
Reservoirs & associated wetlands	Medium	Medium	Medium	High	High	Low	Low	Medium	Medium

(b)

CONFIDENCE	Current loss / stressors	Vulnerability to increasing temperature	Vulnerability to pathogens	Vulnerability to invasive species	Restricted to specific hydro-geomorphic setting	Vulnerability to extreme events	Dependence on timing and magnitude of snowmelt	Vulnerability to decreasing baseflows	Likely future impacts of non-climate stressors
Small high-elevation streams	High	High	Medium	High	High	Medium	High	Medium	High
Mid-size streams	High	High	Low	Medium	Medium	Medium	High	Medium	Medium
Rivers	High	Medium	Low	Low	Medium	Medium	High	Medium	Low
High-elevation groundwater-dependent wetlands	High	High	High	High	High	High	Medium	Low	High
Montane groundwater-dependent wetlands	High	High	High	High	High	High	High	High	High
High-elevation lakes	High	High	High	Medium	High	High	Medium	Medium	High
Reservoirs & associated wetlands	High	Medium	Low	High	High	High	High	Low	Low

VI. Species

NatureServe Climate Change Vulnerability Index – Overview

This overview of methods has been synthesized and reprinted, with permission, from Young et al. (2011). The Climate Change Vulnerability Index (CCVI), developed by NatureServe, is a Microsoft Excel-based tool that facilitates rapid assessment of the vulnerability of plant and animal species to climate change within a defined geographic area. See Appendix E for more details. In accordance with well-established practices (Schneider et al. 2007; Williams et al. 2008), the CCVI divides vulnerability into two components:

1. Exposure to climate change within the assessment area (e.g., a highly sensitive species will not suffer if the climate where it occurs remains stable).

2. Sensitivity of the species to climate change (e.g., an adaptable species will not decline even in the face of significant changes in temperature and/or precipitation).

Exposure to climate change is measured by examining the magnitude of predicted temperature and moisture change across the species' distribution within the study area. CCVI guidelines suggest using the downscaled data from Climate Wizard (http://climatewizard.org) for predicted change in temperature. Projections for changes in precipitation are available in Climate Wizard, but precipitation estimates alone are often an unreliable indicator of moisture availability because increasing temperatures promote higher rates of evaporation and evapotranspiration. Moisture availability, rather than precipitation per se, is a critical resource for plants and animals and therefore forms the other part of the exposure measure within the CCVI, together with temperature. To predict changes in moisture availability, NatureServe and partners used the Hamon AET: PET moisture metric as part of the CCVI (Hamon 1961).

Sensitivity is assessed using 20 factors divided into two categories: 1) indirect exposure to climate change; and 2) species specific factors, including dispersal ability, temperature and precipitation sensitivity, physical habitat specificity, interspecific interactions, and genetic factors. For each factor, species are scored on a sliding scale from greatly increasing, to having no effect on, to decreasing vulnerability. The CCVI accommodates more than one answer per factor in order to address poor data or a high level of uncertainty for that factor. The scoring system integrates all exposure and sensitivity measures into an overall vulnerability score that indicates relative vulnerability compared to other species and the relative importance of the factors contributing to vulnerability.

The Index treats exposure to climate change as a modifier of sensitivity. If the climate in a given assessment area will not change much, none of the sensitivity factors will weigh heavily, and a species is likely to score at the Not Vulnerable end of the range. A large change in temperature or moisture availability will amplify the effect of any related sensitivity, and will contribute to a score reflecting higher vulnerability to climate change. In most cases, changes in temperature and moisture availability will combine to modify sensitivity factors. However, for factors such as sensitivity to temperature change (factor 2a) or precipitation/moisture regime (2b), only the specified climate driver will have a modifying effect.

The six possible vulnerability scores for species are:

Extremely Vulnerable: Abundance and/or range extent within geographical area assessed extremely likely to substantially decrease or disappear by 2050.

Highly Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease significantly by 2050.

Moderately Vulnerable: Abundance and/or range extent within geographical area assessed likely to decrease by 2050.

Not Vulnerable/Presumed Stable: Available evidence does not suggest that abundance and/or range extent within the geographical area assessed will change (increase/decrease) substantially by 2050. Actual range boundaries may change.

Not Vulnerable/Increase Likely: Available evidence suggests that abundance and/or range extent within geographical area assessed is likely to increase by 2050.

Insufficient Evidence: Available information about a species' vulnerability is inadequate to calculate an Index score.

Scoring Methods

In most cases, species were analyzed using the CCVI tool. However, due to lack of updated element occurrence records in Colorado Natural Heritage Program database, 19 plant species known to occur in the Gunnison Basin were not ranked using the CCVI tool (see target selection below of a list of these species). The overall vulnerability score for these species is based on professional opinion. Individual scores for climate change vulnerability factors such as dispersal are not reported for these species due to lack of data (thus these species are not included in Appendices F-G).

Scoring Factors in the CCVI

The factors used to generate the CCVI score are listed in the following section. Detailed definitions of scoring categories are listed in Appendix E.

Indirect Exposure to Climate Change

1. Exposure to sea level rise (not applicable to the Gunnison Basin).
2. Distribution relative to natural and anthropogenic barriers.
3. Predicted impact of land use changes resulting from human responses to climate change.

Sensitivity

1. Dispersal and movements.
2. Predicted sensitivity to temperature and moisture changes.
    a. Predicted sensitivity to changes in temperature.

   b. Predicted sensitivity to changes in precipitation, hydrology, or moisture regime.
   c. Dependence on a specific disturbance regime likely to be impacted by climate change.
   d. Dependence on ice, ice-edge, or snow-cover habitats.

3. Restriction to uncommon geological features or derivatives.

4. Reliance on interspecific interactions.
   a. Dependence on other species to generate habitat.
   b. Dietary versatility (animals only).
   c. Pollinator versatility (plants only).
   d. Dependence on other species for propagule dispersal.
   e. Forms part of an interspecific interaction not covered by C4a-d.

5. Genetic factors.
   a. Measured genetic variation.
   b. Occurrence of bottlenecks in recent evolutionary history.

6. Phenological response to changing seasonal temperature and precipitation dynamics.

Documented or Modeled Response to Climate Change

1. Documented response to recent climate change.

2. Modeled future change in range or population size.

3. Overlap of modeled future range with current range.

4. Occurrence of protected areas in modeled future distribution.

Target Selection

Species of conservation concern within the Gunnison Basin were selected from CNHP's database and supplemental CNHP observation data using the following criteria (see Appendix I for species considered but not included due to lack of data):

1. Federally listed Threatened and Endangered species

2. Candidates for federal listing

3. Species petitioned for federal listing

4. State Wildlife Action Plan Tier 1 and Tier 2 Species of Greatest Conservation Need

5. State listed Threatened and Endangered species

6. Globally rare species (species with NatureServe Conservation Status Ranks G1 – critically imperiled, G2 – imperiled, and G3 – vulnerable)

7. Sensitive Species designated by BLM and USFS

The species list was reviewed by species experts with knowledge of the Gunnison Basin (e.g., Gay Austin, Barry Johnston, and Amy Seglund). The number of species by taxon group and global rank addressed in the vulnerability analysis is in Table 9 and the final list of species is in Table 10. Nineteen additional plant species were added that have been documented in the Gunnison Basin (Gay Austin, pers. communication). However, due to the fact that records for these species are not yet included the CNHP database, these species were assessed qualitatively without using the CCVI tool. These species include the following 14 vascular plants: *Astragalus iodopetalus*, *Botrychium furcatum*, *Botrychium paradoxum*, *Carex diandra*, *Carex microglochin*, *Carex scirpoides*, *Eriophorum chamissonis*, *Eriophorum gracile*, *Hippochaete variegata*, *Hirculus prorepens*, *Kobresia simpliciuscula*, *Lomatogonium rotatum*, *Triglochin palustris*, and *Utricularia minor* and five nonvascular plants: *Cladina arbuscula*, *Cladina rangiferina*, *Dactylina madreporiformis*, *Sphagnum angustifolium*, and *Sphagnum girgensohnii*.

For the purposes of this report, the Colorado River cutthroat trout (*Oncorhynchus clarkii pleuriticus*) and the greenback cutthroat trout (*O. clarkii stomias*) were combined and treated at the species level. Years of stocking and re-introductions have resulted in taxonomic confusion at the subspecies level. Metcalf et al. (2007) found that a population of cutthroat trout in the Gunnison Basin is genetically the greenback subspecies rather than the Colorado River subspecies expected based on historical distributions of these fish. Based on input from the Colorado Parks and Wildlife, game species were not addressed individually using the CCVI, with the exception of bighorn sheep; rather were captured in the ecosystem analysis.

Table 9. Number of species by taxonomic group and global status rank included in the vulnerability assessment. See footnote below for rank definitions.

Taxa	# Species	Global Rank	# Species
Plants	50	G1-G2	13
		G3	14
		G4-G5	22
Amphibians	2	G1-G2	1
		G3	0
		G4-G5	1
Birds	10	G1-G2	1
		G3	0
		G4-G5	9
Fish	1	G1-G2	0
		G3	0
		G4-G5	1
Mammals	9	G1-G2	2
		G3	0
		G4-G5	7
Insects	1	G1-G2	1
		G3	0
		G4-G5	0

Global/State Status: G1 – critically imperiled; G2 – imperiled; G3 – vulnerable; G4 – apparently secure, but with cause for long-term concern; G5 – demonstrably secure.

Note on species names: For animals, common names are standardized and, in general, are the most widely used and recognized means of identifying animal species. However, for plants, common names are not standardized, and in some cases, there are many common names for the same species. Therefore, for plants, the preferred approach is to rely on scientific names to avoid confusion. Similarly, where standards exist for treating capitalization of common names (i.e., common names of birds are always capitalized), those standards are followed. Where capitalization standards do not exist, only proper names are capitalized.

Table 10. Species included in the vulnerability assessment of the Gunnison Basin.

Latin Name	**Common Name**	**Global Status**	**State Status**	**Federal Listing**	**Agency Sensitive**	**State Listing**
PLANTS						
Aliciella sedifolia	Stonecrop gilia	G1	S1		BLM/USFS	
Astragalus anisus	Gunnison milkvetch	G2G3	S2S3		BLM	
Astragalus iodopetalus	Violet milkvetch	G2	S1			
Astragalus microcymbus	Skiff milkvetch	G1	S1		BLM	
Astragalus molybdenus	Leadville milkvetch	G3	S2			
Boechera crandallii	Crandall's rock-cress	G2	S2		BLM	
Botrychium echo	Reflected moonwort	G3	S3			
Botrychium furcatum	Forkleaved moonwort	G1G2	S1S2		USFS	
Botrychium minganense	Mingan's moonwort	G4	S2			
Botrychium pallidum	Pale moonwort	G3	S2			
Botrychium paradoxum	Peculiar moonwort	G2			USFS	
Botrychium pinnatum	Northern moonwort	G4?	S1			
Braya glabella var. *glabella*	Arctic braya	G5TNR	S1		USFS	
Carex diandra	Lesser panicled sedge	G5	S1		USFS	
Carex microglochin	Fewseeded bog sedge	G5?	SNR			
Carex scirpoides	Canadian single-spike sedge	G5	S2			
Carex stenoptila	Small-winged sedge	G2	S2			

Latin Name	Common Name	Global Status	State Status	Federal Listing	Agency Sensitive	State Listing
Cirsium perplexans	Adobe thistle	G2G3	S2S3		USFS	
Cladina arbuscula	Reindeer lichen	G5	S2			
Cladina rangiferina (likely to occur in Basin)	Reindeer lichen	G5	S1			
Cryptantha weberi	Weber's catseye	G3	S3			
Dactylina madreporiformis	A lichen	GNR	S1			
Draba fladnizensis	Arctic draba	G4	S2S3			
Draba globosa	Rockcress draba	G3	S1			
Draba rectifructa	Mountain whitlow-grass	G3?	S2			
Draba streptobrachia	Colorado Divide whitlow-grass	G3	S3			
Drosera rotundifolia	Roundleaf sundew	G5	S2		USFS	
Erigeron humilis	Low fleabane	G4	S1			
Erigeron lanatus	Woolly fleabane	G3G4	S1			
Eriogonum coloradense	Colorado wild buckwheat	G2	S2		BLM	
Eriophorum altaicum var. *neogaeum*	Altai cottongrass	G4?T3T4	S3		USFS	
Eriophorum chamissonis	Chamisso's cottongrass	G5	S1		USFS	
Eriophorum gracile	Slender cottongrass	G5	S2		USFS	
Gilia penstemonoides	Black Canyon gilia	G3	S3			
Hippochaete variegata	Variegated scouringrush	G5	S1			
Hirculus prorepens (Saxifraga hirculus)	Yellow marsh saxifrage	G5	SNR			
Kobresia simpliciuscula	Simple bog sedge	G5	S2		USFS	
Lomatogonium rotatum	Marsh felwort	G5	SNR			
Luzula subcapitata	Colorado wood-rush	G3?	S3?			
Machaeranthera coloradensis	Colorado tansy-aster	G3	S3		USFS	
Penstemon mensarum	Grand Mesa penstemon	G3	S3			
Physaria alpina	Avery Peak twinpod	G2	S2			

Latin Name	Common Name	Global Status	State Status	Federal Listing	Agency Sensitive	State Listing
Physaria rollinsii	Rollins' twinpod	G2	S2			
Ranunculus gelidus ssp. grayi	Tundra buttercup	G4G5	S2		USFS	
Sphagnum angustifolium	Narrowleaf peatmoss	G5	S2		USFS	
Sphagnum girgensohnii	Girgensohn's peatmoss	G5	S1			
Sullivantia hapemanii var. purpusii	Hanging Garden sullivantia	G3T3	S3			
Townsendia rothrockii	Rothrock townsend-daisy	G2G3	S2S3			
Triglochin palustris	Slender bog arrowgrass	G5	SNR			
Utricularia minor	Lesser bladderwort	G5	S2		USFS	
AMPHIBIANS						
Anaxyrus boreas boreas	Boreal toad (Southern Rocky Mountain population)	G4T1Q	S1			SE
Lithobates pipiens	Northern leopard frog	G5	S3		BLM/ USFS	SC
BIRDS						
Accipiter gentilis	Northern Goshawk	G5	S3B		BLM/ USFS	
Aegolius funereus	Boreal Owl	G5	S2		USFS	
Amphispiza belli	Sage Sparrow	G5	S3B		USFS	
Centrocercus minimus	Gunnison Sage-grouse	G1	S1	C	BLM/ USFS	SC
Cypseloides niger	Black Swift	G4	S3B		BLM/ USFS	
Falco peregrinus	Peregrine Falcon	G4T4	S2B		BLM/ USFS	SC
*Haliaeeatus leucocephalus**	Bald Eagle	G5	S1B, S3N		BLM/ USFS	ST
Lagopus leucurus	White-tailed Ptarmigan	G5	S4	P	USFS	
Leucosticte australis	Brown-capped Rosy-Finch	G4	S3B,S4N			

Latin Name	Common Name	Global Status	State Status	Federal Listing	Agency Sensitive	State Listing
Melanerpes lewis	Lewis's Woodpecker	G4	S4		USFS	
FISH						
Oncorhynchus clarkii	Cutthroat trout	G4				
INSECTS						
Boloria improba acrocnema	Uncompahgre fritillary	G5T1	S1	LE		
MAMMALS						
Cynomys gunnisoni	Gunnison prairie dog	G5T2	S2	C	BLM/ USFS	
Gulo gulo	Wolverine	G4	S1	C	USFS	SE
Lepus americanus	Snowshoe hare	G5	S5			
Lynx canadensis	Lynx	G5	S1	LT		SE
Ochotona princeps	American pika	G5	S5			
Ovis canadensis	Rocky Mountain bighorn sheep	G4	S4			
Corynorhinus townsendii pallescens	Townsend's big-eared bat subsp.	G4T4	S2		BLM/ USFS	SC
Sorex hoyi montanus	Pygmy shrew	G5T2T3	S2		USFS	
Sorex nanus	Dwarf shrew	G4	S2			

***Analysis considered roost sites only.**

Global/State Status: G1 – critically imperiled; G2 – imperiled; G3 – vulnerable; G4 – apparently secure, but with cause for long-term concern; G5 – demonstrably secure; T – subspecies status; Q – taxonomic uncertainty; B – breeding; N – non-breeding; NR – not ranked. Federal Listing: LE – listed Endangered; LT – listed Threatened; C – Candidate; P – Petitioned. Agency Sensitive: BLM – Bureau of Land Management; USFS – U.S. Forest Service. State Listing: E – state endangered; T – state threatened; SC – Special Concern.

Application of the Climate Change Vulnerability Index to Species in the Gunnison Basin

Biologists with the Colorado Natural Heritage Program and The Nature Conservancy completed the Climate Change Vulnerability Index (CCVI) for target species using CNHP's Biotics database, available published and unpublished literature, and professional judgment. Draft CCVIs were then reviewed by species experts at the Gunnison Basin: Climate Vulnerability Assessment Review Workshop, May 12-13, 2011. Scoring factors related to historic and predicted future climate (temperature, precipitation, and moisture availability) were calculated in GIS using the methods described below. See Appendix E for additional details on scoring methods.

Exposure to predicted temperature increase was calculated using distribution data from CNHP's database and/or other sources, and a climate prediction model averaged over the summer season (June – August) from Climate Wizard, using the high (A2) carbon dioxide emissions scenario. The high emissions scenario was used because it is most similar to current emissions. The analysis period was to the year 2050 (which is actually an average of projections for years 2040 – 2069). The summer season – growing season for plants, breeding season for animals – was used because it was considered the most critical time period for most species.

Exposure to projected drying (integration of projected temperature and precipitation change, i.e., the Hamon AET: PET moisture metric) was calculated using the dataset created by NatureServe as part of the CCVI. Note that NatureServe based their moisture metric calculations on the same Climate Wizard dataset as above, *except* that they used the moderate (A1B) carbon dioxide emissions scenario. Because the modeling methods used by NatureServe were not available, we were unable to recalculate using the A2 scenario, and so used the data as provided. The GCWG climate data team approved this decision because the A1B and A2 scenarios predict similar changes through the mid-21st century, the period used in this analysis. We calculated the percent of each species' range/distribution that falls within each rating category. All calculations used the "summer" (June – August) data subset, except for *Drosera rotundifolia*, an obligate wetland species, which was calculated using the annual average.

The historical thermal niche factor measures large-scale temperature variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature). It is a proxy for species' temperature tolerance at a broad scale. This factor was calculated in GIS by assessing the relationship between species' distributions and historical temperature variation data downloaded from NatureServe. Historical temperature variation was measured as the mean July high minus the mean January low, using PRISM data from 1951-2006, expressed as a single averaged value for the entire species range.

The historical hydrological niche factor measures large-scale precipitation variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area. Ratings for this factor in animal CCVIs were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from Climate Wizard, and subtracting the lowest pixel value from the highest value. For plant species, based on expert input from the Gunnison Basin: Climate Vulnerability Assessment Review Workshop (May 12-13, 2011), finer-scale mean annual precipitation data from the Cochetopa Creek weather station and the Cimarron weather station (Colorado Climate Trends 2011), and historical accumulated precipitation data from the Snotel site at Schofield Pass (National Resource Conservation Service 2011), were used.

Results

Nearly three quarters of the species (74 %; 54/73) analyzed scored as vulnerable to predicted climate change in the Gunnison Basin. See Tables 11-12 for a summary of results, Figure 8 for vulnerability scores by taxonomic group, Appendix F for detailed summary table of the species CCVI results, Appendix G for rationale and references for plant species, and Appendix H for rationale and references for animal species. The most vulnerable groups are plants, amphibians, fish, and insects (note that these last three groups are represented by two, one, and one species, respectively). This is not surprising, given the comparatively limited dispersal ability of plants and small animals such as amphibians and insects (and their host plants/nectar sources), and the dispersal-limiting restriction of fish to aquatic habitats. The Uncompahgre fritillary, the only insect assessed, is limited to small areas in the alpine zone.

The taxonomic groups represented by more mobile species – birds and mammals – scored as less vulnerable overall. Over half the birds and two-thirds of the mammals scored either *presumed stable* or *increase likely*. The most vulnerable birds are Boreal Owl, Gunnison Sage-grouse, White-tailed Ptarmigan, and Brown-capped Rosy-Finch. The owl, ptarmigan, and rosy-finch are high-elevation species that thrive in cooler environments, which is reflected in their physiological thermal niche scores. These habitats are likely to become degraded as conditions become warmer and drier. The ptarmigan and rosy-finch are also dependent upon ice and snow habitats, increasing their vulnerability. Since Gunnison Sage-grouse require mesic conditions for brood-rearing, existing habitats are predicted to become less suitable for this critical life stage. The most vulnerable mammals are lynx, snowshoe hare, and American pika – all high-elevation species with vulnerability scores driven by their limited capacity to adapt to warmer temperatures. These limitations varied from physiological (overheating), mismatches of seasonal coloration due to novel conditions (generally limited or delayed snow), and increased competition and declining habitat area. At the October 2011 workshop, there was considerable discussion about the vulnerability rating for snowshoe hare. The team decided on *highly* vulnerable based on literature noting snowshoe hares were preyed on more when snowmelt occurred earlier. The wide-ranging bighorn sheep, which displays good dispersal ability and an affinity for more open habitat, was scored as *increase likely* (note there were differing opinions regarding the rating for goshawk).

The majority of the plants we analyzed – 43 out of 50 – scored as *extremely high, highly or moderately* vulnerable to climate change; six were ranked as *presumed stable* and one was ranked *increase likely*. Factors that were most likely to contribute to the vulnerability of plants include: poor dispersal capability, restriction to cool or cold environments, physiological thermal niche, restriction to uncommon geologic features or substrates, and dependence on ice and snow. While there is the known ability for some plant species to adapt to change rapidly, there are few data on the species of conservation concern or the groups of plants assessed in this study.

Confidence in Scores

There is uncertainty about what climatic changes will actually occur and how species fitness and population stability will be affected. There is also less confidence in the exposure ratings for species whose distributions are not well understood (e.g., shrews, plant species that occur in the most remote, high alpine areas such as *Aliciella sedifolia* and *Ranunculus gelidus*).

In the results presented in Table 12, we have overridden the automatic CCVI confidence scores to more closely reflect our confidence in how plant species were scored. The confidence ratings presented here reflect our confidence in the overall vulnerability score, but not necessarily in our confidence that each individual factor was scored correctly.

Table 11. Summary of vulnerability assessment results for species by Index Score.

CCVI Score	Number of Species	Percent of Species
Extremely Vulnerable	18	25%
Highly Vulnerable	17	23%
Moderately Vulnerable	19	26%
All Vulnerable Species	**54**	**74%**
Presumed Stable	15	21%
Increase Likely	4	5%
All Presumably Secure Species	**19**	**26%**
Insufficient Evidence	0	0%

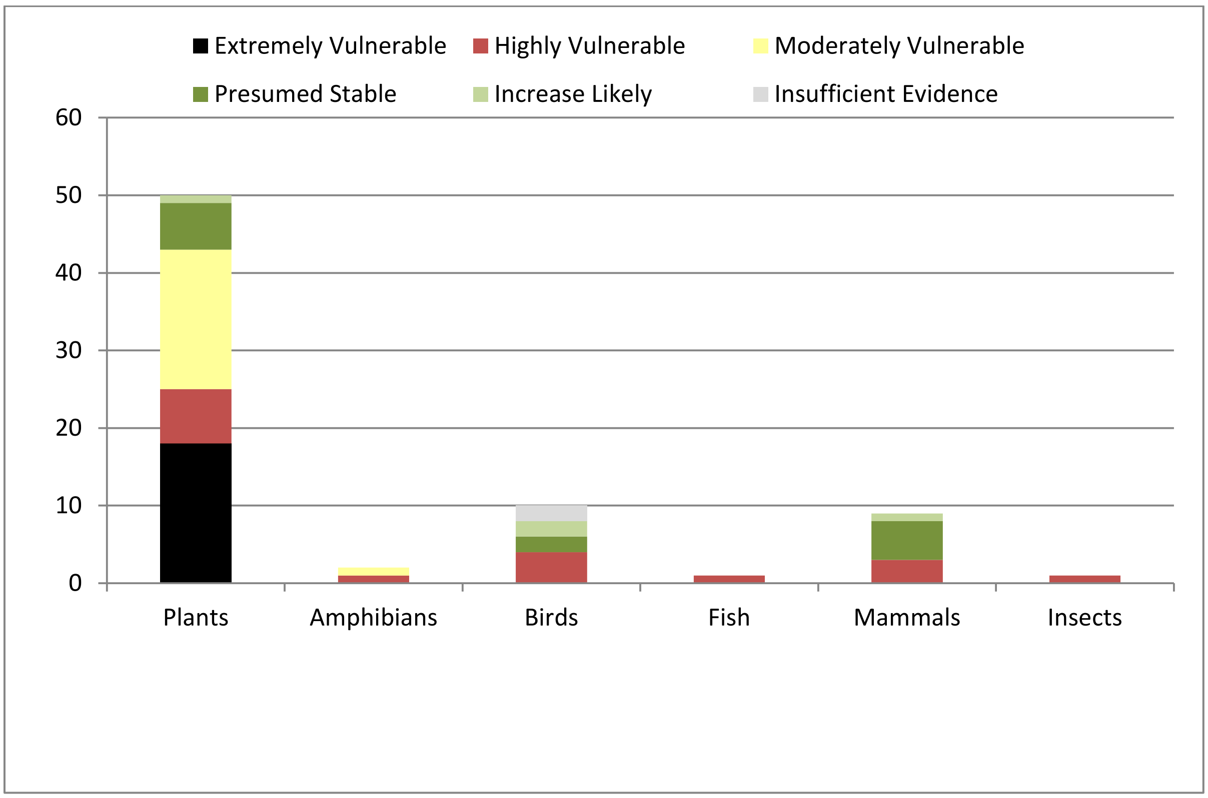

Figure 8. Vulnerability scores of species by taxonomic group.

Table 12. Species climate vulnerability results, associated ecosystem, and confidence score.

Species	Common Name	Ecosystem	Index Score	Confidence
PLANTS				
Aliciella sedifolia	Stonecrop gilia	Alpine	Extremely Vulnerable	L
Astragalus anisus	Gunnison milkvetch	Low elevation sagebrush	Presumed Stable	M
*Astragalus iodopetalus**	Violet milkvetch	Montane sagebrush	Extremely Vulnerable	M
Astragalus microcymbus	Skiff milkvetch	Low elevation sagebrush	Extremely Vulnerable	H
Astragalus molybdenus	Leadville Milkvetch	Alpine	Extremely Vulnerable	M
Boechera crandallii	Crandall's rock cress	Low elevation sagebrush	Highly Vulnerable	L
Botrychium echo	Reflected moonwort	Spruce-fir; Alpine	Moderately Vulnerable	M
*Botrychium furcatum**	Forkleaved moonwort	Spruce-fir	Moderately Vulnerable	L
Botrychium minganense	Mingan's moonwort	Spruce-fir; Alpine	Moderately Vulnerable	M
Botrychium pallidum	Pale moonwort	Spruce-fir; Alpine	Moderately Vulnerable	M
*Botrychium paradoxum**	Peculiar moonwort	Spruce-fir; Alpine	Extremely Vulnerable	H
Botrychium pinnatum	Northern moonwort	Spruce-fir; Alpine	Moderately Vulnerable	M
Braya glabella subsp. *glabella*	Arctic braya	Alpine	Extremely Vulnerable	M
*Carex diandra**	Lesser panicled sedge	Groundwater dependent wetlands (fens)	Moderately Vulnerable	M
*Carex microglochin**	Few-seeded bog sedge	Groundwater dependent wetlands (calcareous fens)	Moderately Vulnerable	M
*Carex scirpoides**	Canadian single-spike sedge	Groundwater dependent wetlands (fens)	Moderately Vulnerable	L
Carex stenoptila	Small-winged sedge	Subalpine riparian	Highly Vulnerable	L
Cirsium perplexans	Adobe thistle	Low elevation sagebrush; Juniper woodlands	Presumed Stable	H
*Cladina arbuscula**	Reindeer lichen	Groundwater dependent wetlands (fens)	Moderately Vulnerable	L

Species	**Common Name**	**Ecosystem**	**Index Score**	**Confidence**
Cladina rangiferina (likely to occur in Gunnison Basin)*	Reindeer lichen	Groundwater dependent wetlands (fens)	Moderately Vulnerable	L
Cryptantha weberi	Weber's catseye	Montane sagebrush	Presumed Stable	L
*Dactylina madreporiformis**	A lichen	Alpine	Extremely Vulnerable	L
Draba fladnizensis	Arctic draba	Spruce-fir; Aspen; Alpine	Highly Vulnerable	L
Draba globosa	Rockcress draba	Alpine	Extremely Vulnerable	M
Draba rectifructa	Mountain whitlow-grass	Lodgepole	Increase Likely	L
Draba streptobrachia	Colorado Divide whitlow-grass	Alpine	Extremely Vulnerable	M
Drosera rotundifolia	Roundleaf sundew	Groundwater dependent wetlands (fens)	Extremely Vulnerable	M
Erigeron humilis	Low fleabane	Alpine	Extremely Vulnerable	L
Erigeron lanatus	Woolly fleabane	Alpine	Extremely Vulnerable	L
Eriogonum coloradense	Colorado wild buckwheat	Alpine; Aspen; Spruce-fir	Highly Vulnerable	H
Eriophorum altaicum var. neogaeum	Altai cottongrass	Groundwater dependent wetlands (fens)	Extremely Vulnerable	M
*Eriophorum chamissonis**	Chamisso's cottongrass	Groundwater dependent wetlands (fens)	Moderately Vulnerable	M
*Eriophorum gracile**	Slender cottongrass	Groundwater dependent wetlands (fens)	Moderately Vulnerable	M
Gilia penstemonoides	Black Canyon gilia	Aspen; Oak and mixed mountain shrub; Spruce-fir	Moderately Vulnerable	M
*Hippochaete variegata**	Variegated scouringrush	Groundwater dependent wetlands (fens)	Moderately Vulnerable	L
*Hirculus prorepens (Saxifraga hirculus)**	Yellow marsh saxifrage	Groundwater dependent wetlands (fens)	Highly Vulnerable	M
*Kobresia simpliciuscula**	Simple bog sedge	Groundwater dependent wetlands (fens)	Highly Vulnerable	L

Species	Common Name	Ecosystem	Index Score	Confidence
*Lomatogonium rotatum**	Marsh felwort	Groundwater dependent wetlands (fens)	Highly Vulnerable	L
Luzula subcapitata	Colorado wood-rush	Groundwater dependent wetlands (fens)	Extremely Vulnerable	H
Machaeranthera coloradensis	Colorado tansy-aster	Montane grassland; montane shrubland	Presumed Stable	L
Penstemon mensarum	Grand Mesa penstemon	Montane sagebrush	Presumed Stable	L
Physaria alpina	Avery Peak twinpod	Alpine	Extremely Vulnerable	H
Physaria rollinsii	Rollins twinpod	Low elevation sagebrush	Presumed Stable	L
Ranunculus gelidus	Tundra buttercup	Alpine	Extremely Vulnerable	L
*Sphagnum angustifolium**	Narrowleaf peatmoss	Groundwater dependent wetlands (fens)	Moderately Vulnerable	L
*Sphagnum girgensohnii**	Girgensohn's peatmoss	Groundwater dependent wetlands (fens)	Moderately Vulnerable	L
Sullivantia hapemanii var. purpusii	Hanging Garden sullivantia	Montane riparian	Extremely Vulnerable	H
Townsendia rothrockii	Rothrock townsend-daisy	Alpine	Extremely Vulnerable	L
*Triglochin palustris**	Slender bog arrowgrass	Groundwater dependent wetlands (fens)	Moderately Vulnerable	L
*Utricularia minor**	Lesser bladderwort	Groundwater dependent wetlands (fens)	Moderately Vulnerable	H
AMPHIBIANS				
Anaxyrus boreas	Boreal toad	Freshwater	Highly Vulnerable	VH
Lithobates pipiens	Northern Leopard Frog	Freshwater	Moderately Vulnerable	VH
BIRDS				
Accipiter gentilis	Northern Goshawk	Spruce-fir	Presumed Stable	Low
Aegolius funereus	Boreal Owl	Spruce-fir	Highly Vulnerable	VH
Amphispiza belli	Sage Sparrow	Sagebrush	Increase Likely	VH
Centrocercus minimus	Gunnison Sage-grouse	Low elevation sagebrush; montane sagebrush; groundwater dependent wetlands	Highly Vulnerable	VH
Cypseloides niger	Black Swift	Rivers	Presumed Stable	VH
Falco peregrinus	Peregrine Falcon	Cliff and Canyon	Presumed Stable	VH

Species	Common Name	Ecosystem	Index Score	Confidence
Haliaeeatus leucocephalus	Bald Eagle	Rivers	Presumed Stable	VH
Lagopus leucura	White-tailed Ptarmigan	Alpine	Highly Vulnerable	VH
Leucosticte australis	Brown-capped Rosy-Finch	Alpine	Highly Vulnerable	VH
Melanerpes lewis	Lewis's Woodpecker	Ponderosa pine; Riparian	Increase Likely	VH
FISH				
Oncorhynchus clarkii	Cutthroat Trout		Highly Vulnerable	VH
MAMMALS				
Cynomys gunnisoni	Gunnison's Prairie Dog	Grassland	Presumed Stable	VH
Gulo gulo	Wolverine	Alpine	Presumed Stable	VH
Lepus americanus	Snowshoe Hare	Spruce-fir	Highly Vulnerable	VH
Lynx lynx	Lynx	Spruce-fir	Highly Vulnerable	VH
Ochotona princeps	American pika	Alpine	Highly Vulnerable	VH
Ovis canadensis	Bighorn sheep	Cliff and Canyon	Increase Likely	M
Corynorhinus townsendii pallescens	Townsend's big-eared bat	Cave	Presumed Stable	VH
Sorex hoyi montanus	Pygmy Shrew	Spruce-fir	Presumed Stable	VH
Sorex nanus	dwarf shrew	Sagebrush	Presumed Stable	VH
INSECTS				
Boloria improba acrocnema	Uncompahgre Fritillary	Alpine	Highly Vulnerable	VH

*Index score assigned by expert opinion; species not analyzed through the CCVI tool.
Confidence Levels: L=low, M=medium, H=high, VH=very high.

Species and Ecosystems

A one to one correlation of ecosystems with plants and animals seldom occurs. Generally we refer to "habitats" for plants and animals, i.e., a place where an organism or a biological population normally lives or occurs. For example, a rare plant habitat may be a rock outcrop that occupies a 100 x 100 m area and this area is within a sagebrush ecosystem but the plant itself is not necessarily tied to sagebrush. For the purposes of this report we have attempted to make this connection to the best of our knowledge but it is important to note that species may or may not consider ecological systems as a critical factor in their life cycle. Numerous studies have documented that species reassemble themselves; tying them to one specific system is not always easy. Clearly there are exceptions to this, e.g., Sage-grouse. Although we have developed several graphs/tables to link the plants and animals to an ecosystem, we urge caution that a strategy for an ecosystem will inherently work for a species within that system. Species can have a vulnerability rating that is not the same as the system that they primarily occur in.

We compared species vulnerability scores with ecosystem vulnerability scores to determine whether or not there were any correlations between species and habitats. Figure 9 depicts the percentage of species within each major ecosystem by vulnerability score. For the purpose of this graph, all riparian and wetland systems were lumped into a "freshwater" category. Two species – bighorn sheep and

Townsend's big-eared bat – were not included. The bighorn sheep occurs within a habitat gradient that covers most of the ecosystems other than that are heavily forested in the Gunnison Basin. The bat frequents many habitats during feeding but during rest and breeding is tied to small-patch habitats (caves and crevices) that are not tied reliably to particular ecosystems. Several species appear in more than one ecosystem.

There is not a strong correlation between species and ecosystem vulnerability in the lower-elevation systems. For example, four of the 11 plants and animals that occupy the sagebrush ecosystem scored *extremely* vulnerable or *highly* vulnerable, yet the system as a whole is expected to remain *stable*, or possibly *increase slightly*. There does appear to be some correlation in the higher-elevation ecosystems, e.g., the alpine system as a whole scored as *highly* vulnerable and most of the species associated with alpine habitats scored *extremely* or *highly* vulnerable. Likewise, spruce-fir forest was scored as *moderately* vulnerable, and 12 of the 13 spruce-fir species scored were *highly* to *moderately* vulnerable. These initial results indicate the need for both coarse and fine-filter strategies for climate change, as some systems and species will most likely respond at different temporal and spatial scales (Claudia Regan, USFS, pers. communication).

There are some discrepancies that need to be explored and addressed further. For example, the freshwater ecosystem high-elevation groundwater dependent wetland ecosystems were rated low vulnerability while several component plant species, e.g., *Drosera and Luzula*, rated as extremely vulnerable.

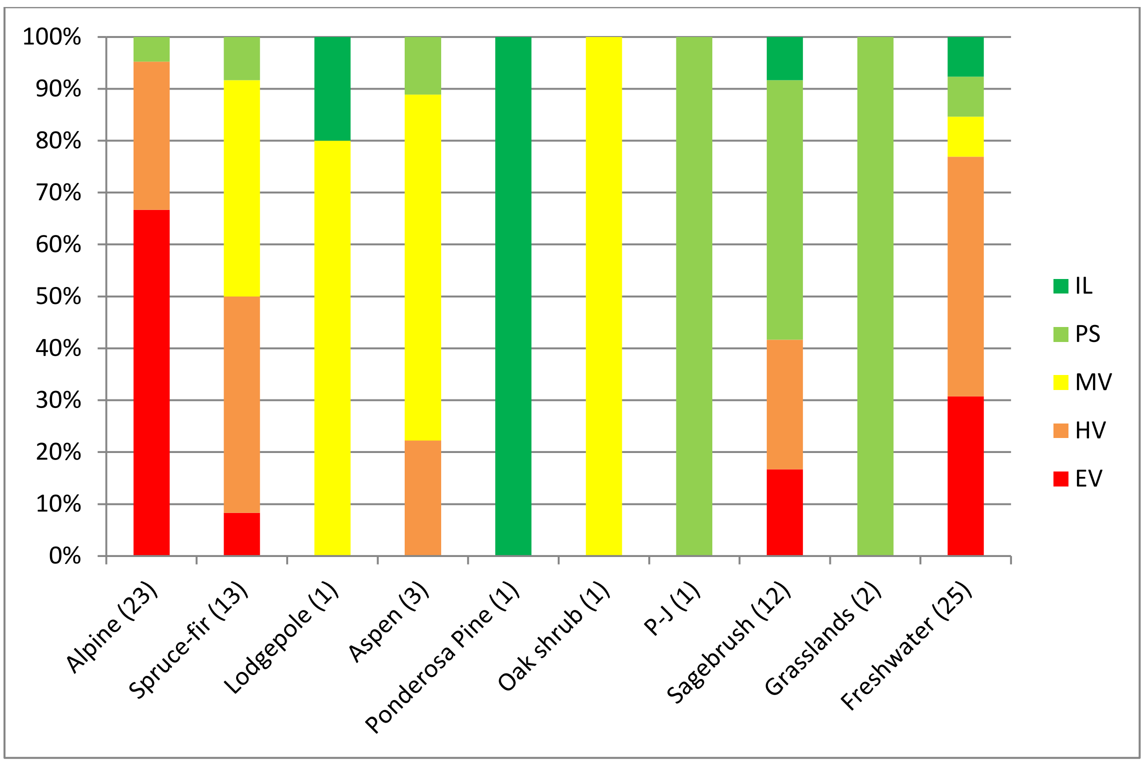

Figure 9. Percentage of species by vulnerability rank and primary associated ecosystem in the Gunnison Basin. Legend codes: IL=Increase likely, PS = Presumed Stable, MV = Moderately Vulnerable, HV = Highly Vulnerable, EV = Extremely Vulnerable.

VII. Social Sectors

Corrie Knapp, University of Alaska, Fairbanks, completed this social resilience and vulnerability assessment during the summer of 2011 as part of a practicum project for The Nature Conservancy and the Gunnison Climate Working Group. This project was intended to compliment the ecological vulnerability assessment (Knapp 2011). The final report is available on the GCWG website at: http://conserveonline.org/workspaces/gunnisonclimatechange.

Methods

Ms. Knapp first reviewed the social, economic and cultural context of the Gunnison Basin to identify relevant livelihoods for interviews and provide an overview of the region. She then conducted 36 interviews with ranching representatives (19) and recreation representatives (16) and one expert on water issues in the Gunnison Basin. These interviews provide the data for this analysis of the resilience and vulnerability of land-based livelihoods to climate change and reveal potential adaptation strategies that will make these livelihoods more resilient to climate change. Ranching representatives included 15 ranchers and four agency representatives. Recreation representatives included 14 business owners and two agency representatives. Ranching operations were cow-calf (47%) or cow-calf-yearling (53%) operations, with several ranches selling hay. Most of the ranchers (86%) were members of families that have been ranching in the Gunnison Basin for two generations, and 53% of them belong to families that have been in the area for over three generations. Since most of the interviewees were over 50, this means that these families often include five or six generations in ranching. About half of the ranchers interviewed had been ranching for over 40 years. Most of the ranchers interviewed (73%) made their incomes entirely in ranching. Agency representatives were interviewed from the BLM, USFS, NRCS and Gunnison County.

Recreation-based businesses included hunting, mountaineering and fishing guides, outdoor gear stores, Crested Butte Mountain Resort, lodging and trail-based businesses. Ms. Knapp interviewed business owners in Gunnison (36%), Crested Butte (43%), Almont (7%), Elk Creek (7%) and Lake City (7%). Most of these business owners (78%) made their livings entirely from their associated business, and 57% of them have been in business in the area for at least 10 years with 21% in business for over 40 years. Agency representatives were interviewed from the BLM and USFS. An interview guide was developed to understand the participants' current business and community context, dependence on the environment, the impact of past weather events, their perception of how projected changes might impact them and suggestions they have about how they might adapt to a changing climate.

Background and Purpose

Climate change projections suggest that the Gunnison Basin will experience increased temperatures and a shift in the timing of precipitation from spring and summer to winter (Barsugli and Mearns 2010). If these projections are correct, there will be rippling impacts for both the ecology and economies of the region. This project reveals how climate change may impact local economies and human behavior, so that we can understand how these factors may interact with climate change to shape habitats, ecological processes, and the abundance and quality of ecosystem services. This project will help to identify climate adaptation strategies that could provide benefits for ecosystems and human communities, as well as highlighting potential tensions between ecological and economic goals.

Resilience

The ranching community is used to dealing with harsh weather and variability, which has made them both adaptable and tenacious. Ranchers have demonstrated innovation and a variety of current adaptations including establishing a local land conservation organization, participating in collaborative efforts and adjusting management practices based on yearly weather variation. Ranching has a long history in the region, and ranchers have developed local knowledge of resources and appropriate use. The community is unified towards current stressors, but multiple pressures and time commitments often overburden ranching leaders. Ranchers' dependence on public land, along with growing recreational pressure, and the potential listing of the Gunnison Sage-grouse constrain their ability to adapt. Ranchers are concerned that the confluence of climate change, increased recreational pressure, and potential listing of the grouse may limit their ability to stay in business. Tension with the broader community also makes ranching livelihoods more vulnerable to climate change because it limits the ability to find creative and adaptive solutions.

Many of the recreation business owners have a diversity of income-generating activities that take advantage of multiple seasons and recreational activities. Those who are diversified may be more resilient to climate stressors at one time of the year. In addition, many recreation-based businesses described how climate change might actually improve both recreation opportunities and visitation as the winters become warmer and more people want to escape high summer temperatures at lower elevations. Recreation-based businesses were vulnerable due to their dependence on tourists and the ski area. While projections suggest improved ski conditions at Crested Butte, people expressed concern about increased dust-on-snow events and the potential for rain-on-snow events. They also expressed concern about the ability of land management agencies to be flexible with recreation permits given potential changes in weather and timing of recreation activities. Finally, many rely on a short season to make most of their income (whether several months of skiing or three months of fishing). This dependence on a certain time of year may make them vulnerable if weather changes during this window of time.

Tipping Points of Concern

For ranchers, the times when climate change impacts will be most stressful are in the spring and summer. In interviews, ranchers described how the spring was already the most challenging time for their operations. Ranchers currently rely on limited spring range, primarily on public lands, in order to get cattle off private lands and begin irrigating hay meadows. Increased temperatures and drying stock water on rangelands may further limit this critical resource, especially if the Gunnison Sage-grouse is listed. Earlier or faster runoff may also make it challenging for ranchers to effectively or efficiently irrigate, especially if federal agencies are inflexible with turnout dates. Since ranchers rely on hay production for winter-feeding, changes in spring temperature and precipitation may impact their ability to overwinter cattle. Reduced moisture during the summer will also impact production on rangelands, impacting cattle weight and potentially leading to curtailing of leases due to drought. Ranchers expressed how potential loss of the use of public lands would make them use private lands more intensively, which may have negative impacts on wildlife species. They also expressed how several consecutive years of drought would make it challenging for them to stay in business.

While many recreation businesses felt that increased winter precipitation may help them, they were also concerned about increased extreme weather events, the impact of drought on the recreation experience, and a potential increase in recreation pressure. Extreme weather events may make it difficult for tourists to travel to the Gunnison area and may increase danger related to avalanches and flooding. Earlier snowmelt may decrease wildflowers, degrade the quality of the fishing and biking experience and lead to hotter conditions and increased fire risk. Recreation businesses also felt that climate change in other areas could lead to an increase in tourism in Gunnison, as people flee hotter temperatures elsewhere. Increased recreation pressure may make it more difficult for recreation businesses to continue to offer a quality experience.

Social Sector Conclusions

Climate change will impact both livelihoods and ecosystems in complex and interconnected ways. In order to understand the best strategies for climate adaptation planning, it is critical that we understand how ecosystems and livelihoods might respond to changes and what types of opportunities and challenges arise from these changing dynamics. The ranching community has adaptive strategies for dealing with the extreme and variable climate, a strong community and a long history in the region; however they are vulnerable to climate change because they depend on public lands, have increased potential for tension with other community members, and have multiple stressors that challenge their ability to survive in the ranching industry. Recreation businesses have diverse livelihood strategies, but are dependent on the economic climate and the ski area. Climate change projections suggest both benefits and challenges for land-based livelihoods. While the increased duration and intensity of droughts may place additional stress on area ranches, climate impacts to other locations may make Gunnison more attractive to tourists and increase recreation pressure in the Basin.

VIII. Data Gaps

Little primary research has been conducted to date on many of the targeted Gunnison Basin ecosystems and species of conservation concern in the context of climate change. Exceptions include US Forest Service and Rocky Mountain Biological Laboratory research on aspen, conifers, montane sagebrush, selected subalpine and alpine plant and animal species, e.g., marmot, Aspen sunflower. For both plants and animals, the most significant data gaps are related to inter-specific interactions, genetics, inherent adaptability, and documented or modeled response to climate change. Specifically, relationships among rare plants, symbiotic species (e.g., mycorrhizae, pollinators), and seed dispersers is poorly understood. Furthermore, crucial life history information for most plant species is unknown. It is likely that some of the plant species of concern have limited pollinator versatility, and are dependent on other species to disperse seeds or spores. Thus, our scoring reflects the paucity of data on these species. Data on measured genetic variation were available for only two out of the 50 plant species we analyzed. Data gaps also include indirect effects of climate change (i.e., climate change effects on one species that then drive changes in other species) and interactions between changing climate and other stressors (e.g., habitat fragmentation).

For migratory species, whose habitat changes throughout their life history, it is important to consider possible effects in all habitats (e.g., breeding and wintering grounds), and how changes in one habitat might influence species’ use of other habitats. For most ecosystems, it is unclear whether key species have sufficient adaptive capacity to survive as the climate changes. It would be useful to land and water managers to identify indicators to monitor trends in ecosystems.

For most ecosystems, it is unclear whether key species can and will move at the needed rate to keep up with climate change. Lag times exist between when climate changes which makes germination difficult and when adults die, thereby changing the ecosystem type. Identifying indicators to measure the response of ecosystem and species to climate change would be most helpful for natural resource managers.

Preliminary research needs include:

1. Better understanding of life history, genetics, reproductive biology, and pollination ecology of species.
2. Documentation of climate-related changes in phenology, distributional shifts, and alteration of habitats for plants and animals of concern is lacking.
3. Identification of climate variables important for plants and current role of climate to help understand/anticipate effects that future climate change may have.
4. Better understanding of interactions among climate change and other stressors.
5. Greater understanding of the inherent adaptability (genetic and physiological) of individual species.
6. Identify important wildlife corridors to ensure connectivity between habitat areas and to facilitate the ability of species to shift ranges in response to climate change.
7. Field investigations focused on changing local climate conditions, associated habitat condition, and actual species response.
8. Research is needed on current range and distribution of lesser known species (e.g., shrews, high alpine plant species such as *Aliciella sedifolia* and *Ranunculus gelidus*).
9. Future investigators should consider using historical climate data, if possible, to score the historical thermal niche, physiological thermal niche, and historical hydrological niche categories for assessing species vulnerability using the CCVI tool. Data from the local climate stations within the study area would provide a finer scale approach to vulnerability scoring.
10. Increase resolution of projected climate data. Lack of climate data from local alpine regions is problematic as it is much harder to associate vegetation changes with climate.

Further work is needed to clarify and prioritize this preliminary list of research needs.

IX. Conclusions and Recommendations

This vulnerability assessment is a first attempt at identifying ecosystems and species of the Gunnison Basin that are likely to be affected by climate change and why they are at risk. The results indicate that many of the natural features of the Basin (50% of ecosystems and 74% of species of conservation concern) are susceptible to loss, degradation or other changes induced by warming temperatures. Climate projections suggest that the natural environment, ecosystems, and species of the Gunnison Basin will change significantly over the next several decades. While we have high confidence that ecosystem changes will occur, we have less confidence regarding the temporal and spatial scale of those changes. Adaptation strategies will need to consider lag effects, soil type, species competition, and other considerations.

Adaptation strategies should also consider the key factors contributing to the vulnerability of terrestrial ecosystems and species, e.g., pest attacks, invasive species, fire, and drought, and factors contributing to the vulnerability of freshwater ecosystems, e.g., decreasing base flows, dependence on timing and magnitude of snowmelt. Climate change is predicted to significantly affect the frequency and severity of disturbances, e.g., fire and/or pest attacks, that drive ecosystems. Additionally, while climate is predicted to impact ecosystems and species, other factors such as land use and invasive species, are likely to play an important role. Adaptation strategies must consider these and other stressors.

While it is important to fill key data gaps and reduce uncertainty about climate change impacts, the climate is already changing, and its ecological effects are already emerging. These changes, given the current rate of emissions of greenhouse gases, are likely to accelerate and to cause significant changes in ecosystems and livelihoods. Accordingly, we need to begin taking action, building on what we know, to help to build resilience for the species, ecosystems, and people facing a changing climate. Actions should include establishment of monitoring programs to better detect and evaluate responses of ecosystems and species to climate change.

This report provides a foundation for the Gunnison Climate Working Group's next step: developing adaptation strategies to help resilience of species, ecosystems and people adjust to a changing climate in the Gunnison Basin. These adaptation strategies may change the priority, rate, timing, or location of specific actions in the management of natural resources, ranches, recreation, etc. One important step will be to integrate the ecosystems and species results with the social vulnerability/resilience assessment to help develop a robust set of strategies to reduce the adverse effects of climate change on people and ecosystems, especially where climate change impacts are inter-related.

Finally, climate adaptation planning is a relatively new endeavor and it is important to document and learn from the process. We will work with the Gunnison Climate Working Group, the Southwest Climate Change Initiative, and Southern Rockies Landscape Conservation Collaborative to share methods, results and lessons learned across the Gunnison Basin and the region.

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GUNNISON BASIN
CLIMATE CHANGE VULNERABILITY ASSESSMENT
APPENDICES

Southwest
Climate Change Initiative

APPENDIX A: Climate Change Exposure

Authors: Joseph Barsugli, Western Water Assessment, and Jamie Robertson, The Nature Conservancy

Summary

The climate of the Gunnison Basin is projected to get warmer over the next few decades as part of a larger pattern of warming in the western United States. Precipitation is projected to stay the same or increase in the winter, and to decline in the spring and summer, though precipitation projections are considerably less certain than the temperature projections. The warmer temperatures lead to earlier snowmelt and stream flow peaks, as well as a shorter snow season and longer growing season. The warmer temperatures also lead to more use of water by natural vegetation and greater loss of soil moisture in summer. Current model studies project a decline in the annual volume of stream flow.

Global Change and Local Impacts

Climate change is a global phenomenon, but its impacts can vary from place to place. Scientists use observed climate data and climate model simulations at multiple scales, from global to regional to local levels to measure impacts from observed changes and to assess potential threats to species and ecosystems from future changes. One of the main activities of climate science over the past thirty years has been to ask whether or not the observed trends in temperature, precipitation and other climate variables have been out of the ordinary (*detection* of the trend), and whether or not these trends are likely due to the increasing amount of greenhouse gases in the atmosphere (attribution of the trend). The answer to these questions depends on how big the trends are compared to the natural variations in climate, and how good an observational record exists in a given location. Clear changes in the climate typically appear first in temperature and for averages over large regions and long time periods, before they are detectable at any given location.

In this section, we present a brief summary of the global context of climate change, regional climate change in the western United States, and specific projections for the upper Gunnison River watershed. We will see that the overall warming in the Gunnison (Figure 1) is part of a larger pattern of warming in the western United States that is likely to continue.

According to the International Panel on Climate Change Fourth Assessment Report (IPCC 2007), the mean annual global temperature has unequivocally warmed over the past century, and this warming is very likely due to the accumulation of greenhouse gases (GHGs), such as carbon dioxide, in the atmosphere from human causes. The observed warming has been especially rapid since the late 1970s. One consequence of this warming is that the extent of Northern Hemisphere snow cover has decreased, especially in springtime. The amount of greenhouse gas in the atmosphere will almost certainly increase in the next two decades and, under several possible scenarios, continue to increase at a high rate over the rest of the 21st century. The result would likely be human-caused warming continuing through the 21st century.

There have been observed changes in the water cycle, particularly those aspects that are closely related to temperature. Many locations in the West have experienced more precipitation falling as rain rather than snow, earlier snowmelt and runoff, and reductions in springtime snowpack. Several peer-reviewed studies have attributed the west-wide pattern of these hydrologic changes to GHG increases (Das et al.2009; Bonfils et al. 2008; Pierce et al. 2008; Hidalgo et al. 2009). The situation is more complicated in the high-elevations of Colorado Rocky Mountains, including the Gunnison Basin that is dominated by winter and early spring precipitation. The relatively small amount of warming that has been observed so far does not push the average wintertime temperatures above freezing, so the hydrologic cycle has not yet been strongly affected (Regonda et al. 2005). Yet there is some evidence that temperature has played a role here too, particularly during the late spring (Clow 2010). With the larger changes that are projected for the future, even the high elevations are not immune from change. For areas above 9,000 feet elevation, Christensen and Lettenmaier (2007) project up to a 15% decline in total snowpack by mid-century and up to 30% decline by the end of the century. A complicating factor for the hydrology of the Colorado Rocky Mountains is that the timing of runoff has also been affected by wind-borne dust from the Colorado Plateau that makes the snow darker, and, along with warmer temperatures, results in earlier snowmelt and more rapid runoff (Painter et al. 2010). Understanding whether the sources of dust will increase in a warmer climate, and how dust and warming work together to alter the snowpack are areas of current research.

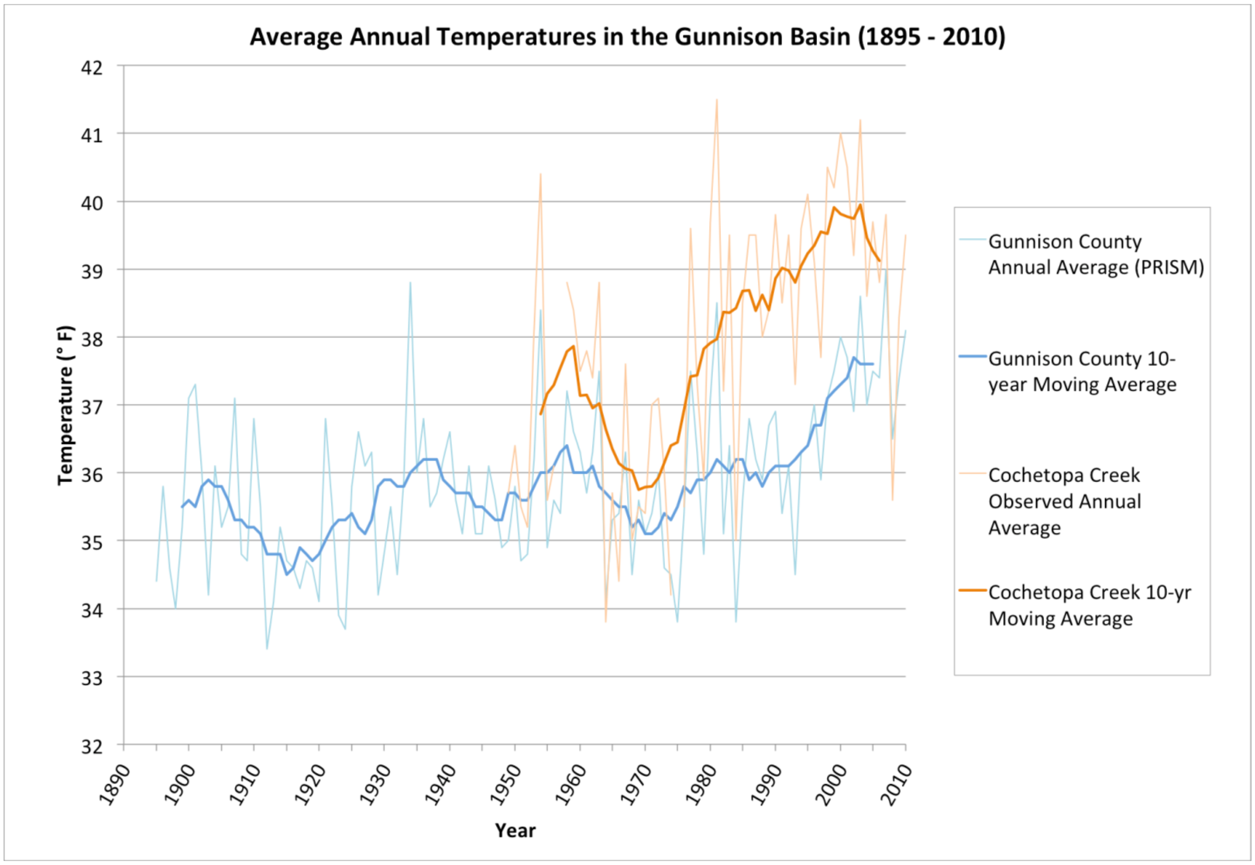

Figure 1. Annual average temperature in the Gunnison Basin. The annual average and 10-year moving average temperature for Gunnison County (blue) computed from the PRISM dataset, uses a statistical model to blend temperatures at observing stations to create a county-wide average. For comparison, the temperatures at the Cochetopa Creek Cooperative Observer Network site are shown. This site is identified by the Colorado Climate Center as having a record of consistent observation quality. Data source: Colorado Climate Center and Western Regional Climate Center.

The Future of the Gunnison Basin

We used several sources of information to develop scenarios of the future climate of the Gunnison Basin. The first source is from the North American Regional Climate Change Assessment Program (NARCCAP) wherein multiple regional climate models (RCMs) are driven with multiple global climate models (GCMs) to produce higher spatial resolution (50 km) scenarios of climate change over most of North

America (Mearns et al. 2009). These models support the IPCC projections in the central Colorado Rocky Mountains, including the Gunnison Basin. They show a clear upward trend in temperature during the current and future time periods (1971-2000 and 2041-2070 respectively), with the mid-century being about 3°C (5.4 °F) warmer than the recent past (Barsugli and Mearns 2010). For precipitation, neither period exhibits a distinct trend, but on average, a decrease in precipitation in the future of 7% is projected. Figures 2a and 2b illustrate these findings with the yearly results from one of these RCM simulations, the Canadian RCM (CRCM) nested in the Canadian global model (CGCM3). These graphs underscore the fact that year-to-year and decade-to-decade climatic variability will still be observed in the future. That is, we do not expect each year to be warmer (or dryer) than the previous year. Only after a number of years does it become clear that the climatological average has shifted. Climate variations will still be an important factor for ecosystems and species in the future. The concern for the Gunnison Basin is that the long-term trends will make the warmer extremes warmer than anything observed, and very possibly make the drier extremes even drier.

These projections through the middle of the 21st century are driven by the IPCC's A2 emissions scenario, a more extreme scenario of GHG emissions described by the IPCC (2007) as the result of "a very heterogeneous world with high population growth, slow economic development and slow technological change." Readers should take care not to confuse emissions scenarios with the climate scenarios represented by model simulations described in the paragraphs above and below. Most emissions scenarios that were analyzed by the IPCC show a comparable magnitude of climate change out to 2050. However, after that time, the higher emissions scenarios such as the A2 scenario considered here result in considerably greater climate change than the lower emissions scenarios.

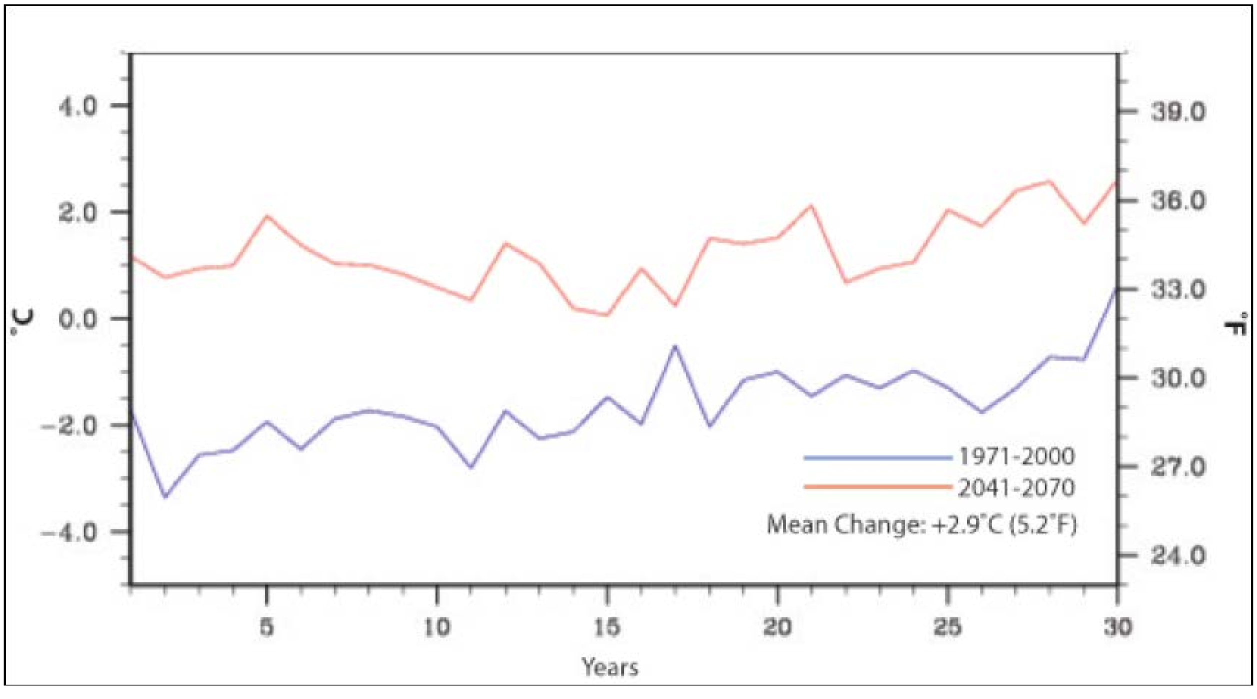

Figure 2a. Temperature projections from a regional climate model over the central Colorado Rocky Mountains. The results are from the CRCM (50 km resolution) embedded in the CGCM3 forced by the A2 emissions scenario. The blue line shows the simulation for the 30-year period 1971-2000, and the red line the projection for the 30 year period 2041-2070.

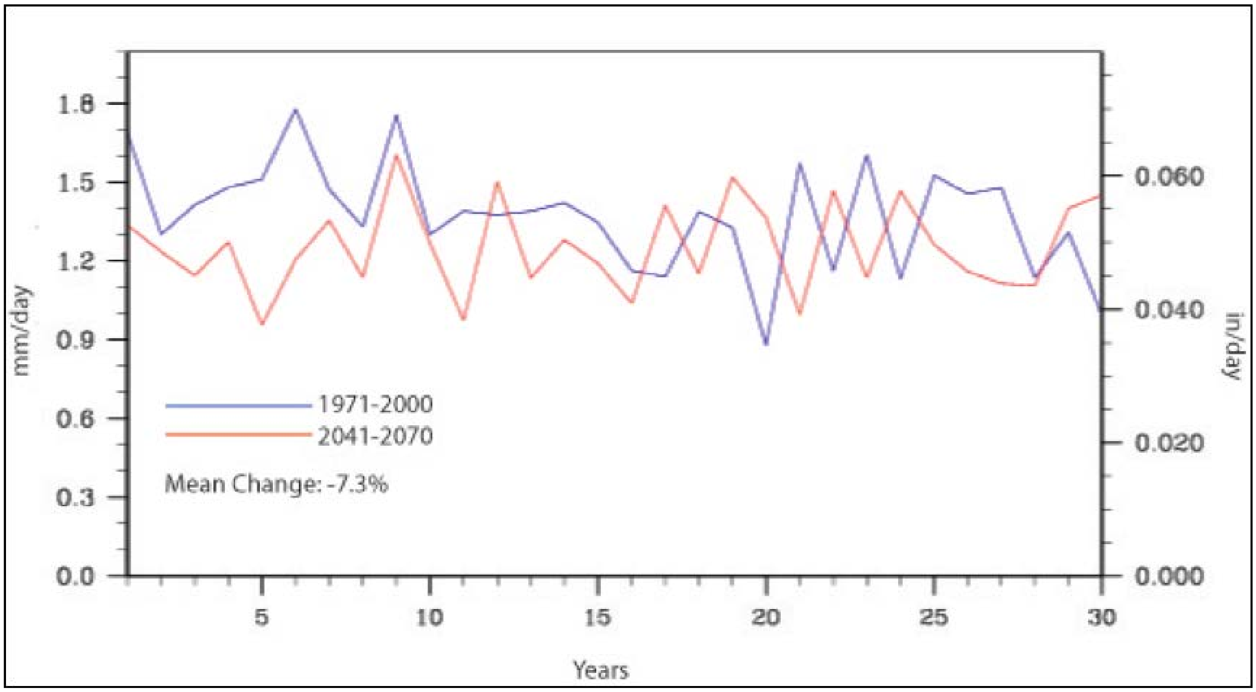

Figure 2b. Precipitation projections from a regional climate model over the central Colorado Rocky Mountains. The results are from the CRCM (50 km resolution) which was used to downscale the CGCM3 forced by the A2 emissions scenario. The blue line shows the simulation for the 30-year period 1971-2000, and the red line the projection for the 30 year period 2041-2070. Note that the model's simulation of the historic climate does not necessarily line up year-for-year with the observed climate; it is only intended to simulate the climate averages, trends and other statistics.

Changes in seasonal climate patterns add another level of complexity, and the differences between projections for winter and summer are important for the Gunnison Basin. Two modeled scenarios of how the Gunnison Basin's climate might change were developed for the first Gunnison Basin climate change adaptation workshop and were considered (along with other information) in the vulnerability assessments. Table 1 (Barsugli and Mearns 2010). The NOAA Geophysical Fluid Dynamics Laboratory (GFDL) AM2.1 simulation and the NOAA GFDL AM2.0 simulation were chosen to represent a "moderate" and a "more extreme" level of change respectively from among the many global and regional climate model projections investigated. Like all the GCMs, these have a spatial resolution of approximately 2.5 degrees (about 250 kilometers per side of each grid-cell), and the four grid-cells covering the western portion of Colorado (including the Gunnison Basin) were used for the calculations described here. In both scenarios, average temperature increases during all seasons, and annual precipitation stays the same or decreases. Temperature increases most in summer, and precipitation decreases most in spring and summer. In the moderate climate scenario there is an increase in wintertime precipitation. These seasonal changes are vitally important relative to species phenology discussed in other sections of this report and for recognizing summers to be the future periods of greatest ecological hardship.

Table 1. Two scenarios of seasonal precipitation and temperature changes from periods 1950-1999 to 2040-2060 for the Gunnison Basin. These two scenarios were developed for the Gunnison Climate Change Adaptation Workshop (Neely et al. 2010) from the range of available global and regional climate model projections for the central Colorado Rocky Mountains. The Moderate change scenario (GFDL AM2.1 GCM) is near the median of the model projections. The More Extreme scenario (GFDL AM2.0 GCM) lies in the top 25% of model projections, and is by no means the most extreme of the climate model projections (Barsugli and Mearns 2010).

	Moderate Scenario			More Extreme Scenario		
Season	Precipitation (percent)	Temp °F	Temp °C	Precipitation (percent)	Temp °F	Temp °C
Annual	~0.0	+3.6 to +5.4	+2.0 to +3.0	-10.0	+5.4	+3.0
Winter	+15.0	+3.6	+2.0	~0.0	+5.4	+3.0
Spring	-12.0	+4.5	+2.5	-15.0	+5.4	+3.0
Summer	-15.0	+5.4	+3.0	-20.0	+7.0	+4.0
Fall	+4.0	+4.5	+2.5	-10.0	+5.4	+3.0

The Gunnison Basin has complex topography and micro-climates that are not well-represented in the global and regional climate models. However, it is likely that temperature and precipitation changes within the project area will vary due to elevation gradients and localized processes such as cold air drainage in glacial valleys. In the absence of detailed modeling, we assume that the same warming is likely to occur everywhere. It should be noted that some research for mid-latitude locations indicates larger warming has already occurred at high elevations (Diaz and Eischeid, 2006) – particularly near the level of the average snow-line (Pepin and Lundquist 2007). However, this statement must be moderated by two considerations: First, there are very few reliable long-term temperature records at high elevations, and second, trends in Colorado have been relatively small so that, temperatures are still low enough that changes in snowpack have been small (Regonda et al. 2005) and therefore the feedback between reduced snowpack and increased warming has been weak.

Hydrologic Changes

In addition to changes in mean annual temperature and precipitation, changes in hydrology are a major concern in the Gunnison Basin. There is no evidence for a long-term trend in the annual volume of water for the USGS stream gage on the Gunnison River near Gunnison, Colorado (US Geological Survey 2010); however, such a trend would be hard to detect against the background of year-to-year variability in the stream flow (See Figure 3). Based on general principles, increasing temperature leads to a later start of the snow season, earlier snowmelt, runoff and peak runoff, and greater evapo-transpiration (ET) from plants and the ground. The increase in wintertime precipitation seen in many climate model simulations can counteract some of these tendencies however. The balance between increased ET and the seasonal changes in precipitation is critical for determining whether the annual volume will increase or decrease. Spatially detailed hydrologic modeling studies using inputs from climate model projections let us estimate the relative importance of these terms and get quantitative estimates of how the average hydrograph will change.

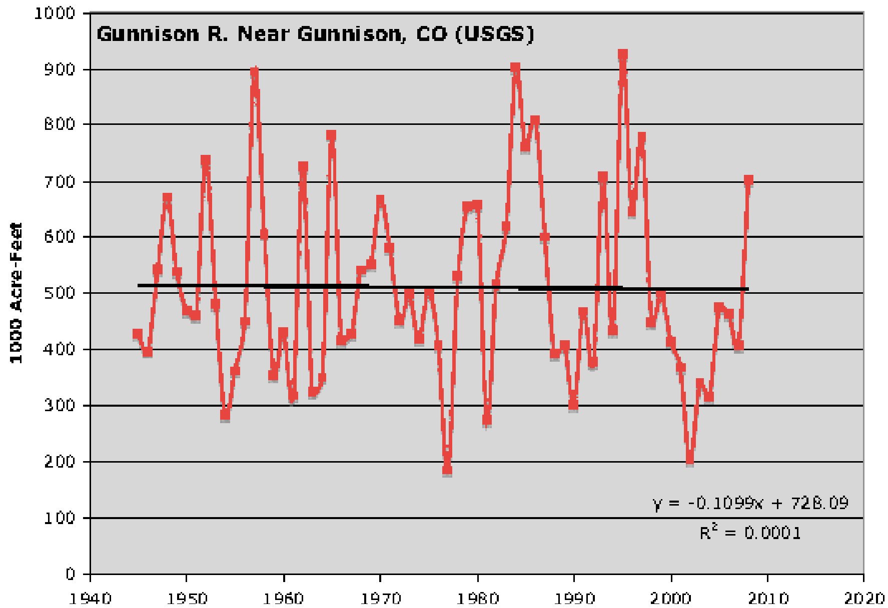

Figure 3. Observed annual streamflow (in red) for the Gunnison River near Gunnison, Colorado, 1945-2008. Because consumptive use, storage, and diversions of water to other basins are small compared to the annual flow, the gaged flow can be used for long-term trend analysis. However, no significant trend is seen (in black), due to the large variation in flow from year to year.

Several such studies investigate how flows in the Gunnison Basin might change in the future. Barsugli and Mearns (2010) based their two hydrologic scenarios on modeling done by the US Bureau of Reclamation using the Sacramento/Soil Moisture Accounting hydrologic model. Results of the moderate scenario show a 5-10% decline in annual runoff and peak runoff shifting seven days earlier. The more extreme scenario shows a 20-25% decline in annual runoff and 14+ days shift earlier peak runoff. Since that report three additional hydrologic modeling studies on the upper Gunnison River, or its tributaries, have been published: the Secure Water Act report (US Bureau of Reclamation 2011), The Colorado River Water Availability Study (Colorado Water Conservation Board 2010), and a study by USGS scientists on the East River tributary (Battaglin et al. 2011). These four studies in total, using three different hydrologic models, tell much the same story: the average of the models shows a decrease in annual flows of 10 – 25%, earlier runoff and peak flows ranging from a week to about a month earlier, decreased spring snowpack, and dryer soils and lower flows in the summer. Battaglin et al. (2011) note the decreased recharge of groundwater as well.

Given the qualitative similarity of the above studies, we show only results from the US Bureau of Reclamation (2011) study. This study used the VIC hydrology model (references may be found at http://www.hydro.washington.edu/Lettenmaier/Models/VIC/) forced by downscaled monthly climate projections. This model has a spatial resolution of approximately 12 km, and each grid-cell is divided into five elevation bands to better simulate the snowpack. The hydrologic simulations as well as the climate model projections used to drive the simulations are available online at http://gdo-dcp.ucllnl.org/downscaled_cmip3_projections/. The annual total runoff is shown for the Gunnison River basin above Blue Mesa reservoir in Figure 4a. The heavy black line shows the average over all the available model simulations, with a 20-year moving average applied to highlight the long-term trend. While there is very little trend during the period 1950-1999, there is a decline of about 15-20% by the end of the 21st century. The time traces for the 36 individual model simulations that sent into the model average are shown to indicate that large annual variability will continue into the future. The seasonal shift to earlier runoff in the monthly hydrograph is shown in Figure 4b. The average over all the model simulations for the snow water equivalent (SWE) for March 1, April 1, May 1, and June 1 is shown in Figure 5.

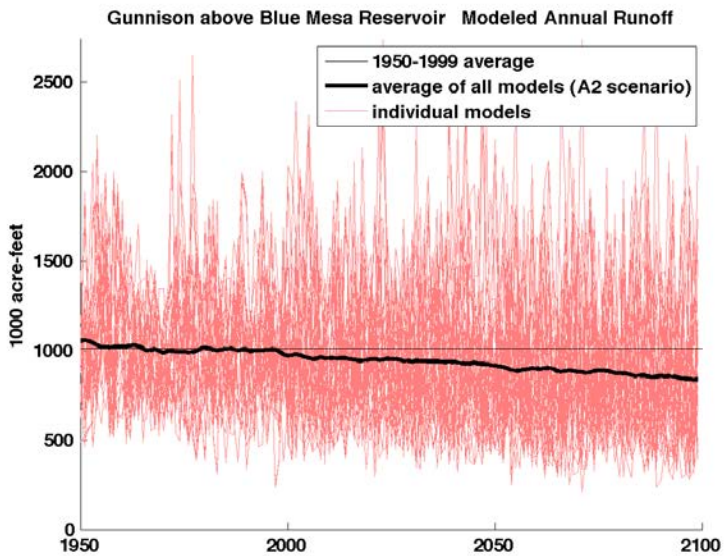

Figure 4a. Annual total runoff for the Gunnison River basin above Blue Mesa reservoir as simulated by the VIC hydrologic model using climate model inputs. Only available model simulations using the A2 emissions scenario are shown. The heavy black line shown the average over all the available model simulations, with a 20-year moving average applied to highlight the long-term trend. Individual model simulations (data source: US Bureau of Reclamation 2011).

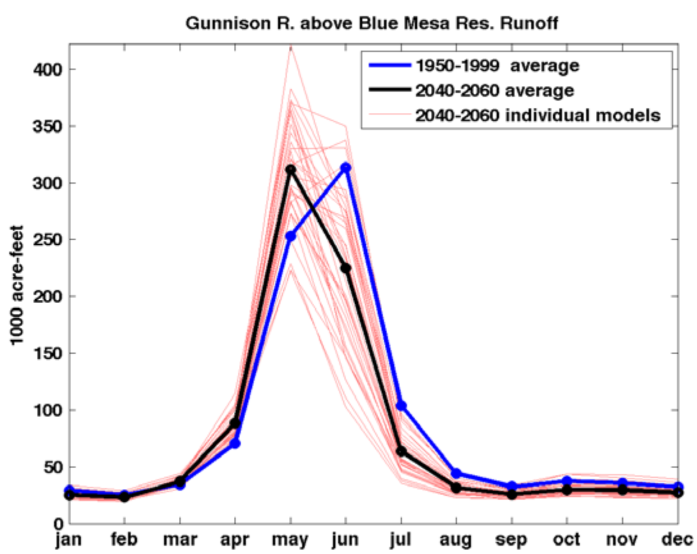

Figure 4b. Projected monthly hydrograph for the Gunnison River basin above Blue Mesa reservoir for 2040-2060 compared to the modeled average 1950-1999 hydrograph. The individual model simulations (red) show a large range of possible future flows, but they all show earlier runoff.

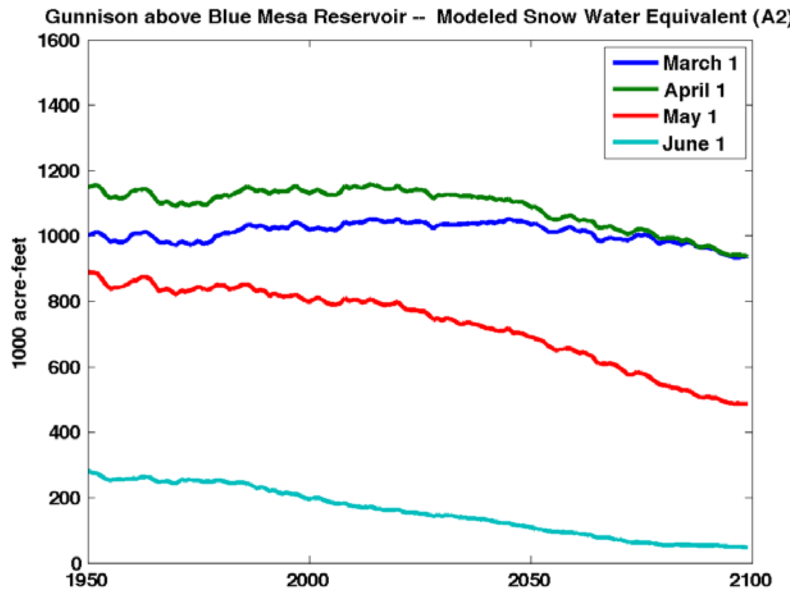

Figure 5. The decline in spring snowpack is depicted by time series of the snow water equivalent (SWE) from the VIC model simulations (US Bureau of Reclamation 2011). The SWE is expressed as the total snow water volume in the Upper Gunnison basin and only the average over all model simulations using the A2 scenario is shown. A 20-year moving average is applied to the data to highlight the long-term trends. Declines are greatest in May and June.

Snowmelt, runoff and stream flow shift earlier in the year at all elevations, but the impacts on the role of hydrology in the ecosystem can vary. The hydrology of high elevations is dominated by snowmelt. The melt season is projected to start a few weeks earlier, starting from roughly the same amount of water in the snowpack. Some features depend on groundwater flow, such as seeps, springs, and fens. The hydrologic models investigated here only calculate local soil water storage and do not explicitly calculate groundwater flows or water tables. For this vulnerability analysis, hydrologic factors such as the level of the water table in alpine wetlands were inferred from simple conceptual models or expert judgment. The hydrologic modeling results are presented here mainly to inform the broader context from which the two hydrologic change scenarios were generated. As noted below, the CCVI method uses an index of vegetative moisture stress that is calculated from a very simple water balance model with a fixed water holding capacity of the soil. The monthly temperature and precipitation inputs to this model were derived from a large selection of climate models, but only the median result was used in the CCVI. The set of climate models used to drive the climate wizard moisture index and those used to drive the VIC hydrology model include many of the same simulations. As a consequence, the results of the two methods are qualitatively similar to those of the hydrologic models, with increased drying and moisture stress in the growing season.

Drought

Drought is a natural part of the climate of the Gunnison region. Drought has many definitions and many dimensions, and we can only touch on a few of these here. Drought is sometimes defined as a lack of precipitation, but other factors such as temperature and the timing of precipitation have a role in determining the severity of the impacts of drought. How is drought projected to change in the future? Warmer temperatures will increase the severity of drought impacts. Drought impacts would hit earlier during the spring and summer, with greater depletion of soil moisture, and therefore more stress on ecosystems. Warmer temperatures could also lead to more severe declines in summer and fall stream flow. This relationship between temperature and the severity of drought impacts has already been observed in the West (Breshears et al. 2005).

The projected seasonal shift in precipitation and runoff would also lead to greater impacts of drought in the summer. At lower elevations, summer rains are a large contributor to the total precipitation, so that the projected decline can have a proportionately larger impact. Some of the climate model simulations (including the "more extreme" scenario above) show overall decline in annual precipitation, indicating a higher risk for drought.

The paleo-climate record clearly shows that there have been numerous multi-year and multi-decade droughts in Colorado River basin (Meko 2007). There is, however, not yet much confidence in the ability of the climate models to project changes in the duration and frequency of these long-term droughts.

Dust on Snow Events

Another factor affecting hydrology relative to climate in the Colorado Rocky Mountains which likely is augmenting GHG-induced climate change impacts is the increase in dust-on-snow events since the mid-1800s (Painter et al. 2010; Deems and Lucas 2011). Anthropogenic disturbances (such as livestock grazing, agriculture, road and site grading, and vehicles) on western US aridlands loosens soils allowing winds to carry and deposit abnormal quantities of dust onto snow-covered Colorado mountains. The dust decreases the snow's albedo – it makes the snow darker – so that it reflects less sunlight and absorbs more solar energy. The result is a faster rate of snow melt, shorter snow cover duration, earlier and potentially larger peaks in streamflow, and reduced annual runoff. Recent research in the Upper Colorado River Basin shows peak runoff to occur by an average of 3 weeks earlier and annual runoff to be decreased by about 5% in dust-loading years (Painter et al. 2010). Both dust and warmer temperatures act to advance the timing of runoff and decrease the total runoff. However, the current state of hydrologic modeling has only considered these effects separately. The projections based on climate models (including those used in this report and the CCVI) only account for the changes due to warming.

Exposure and Vulnerability

Change is likely to lie outside the range that has been experienced by the ecosystems and will likely occur rapidly compared to historical rates of change. The various climate models and scenarios of human development offer a range of possible outcomes we can prepare for or try to prevent. What are the implications of these outcomes to biodiversity? As the Earth heats up or cools down and its air and soils become dryer or wetter, ecological responses vary with different levels of change. Vulnerability of species or ecosystems typically increases when climate changes are greater and require more extreme adaptive responses than are normal. Determining biodiversity vulnerability to climate change requires knowledge of variables such as increases in air temperature or decreases in soil moisture. When quantified, these variables are known as *exposure* data.

The Gunnison Climate Working Group investigated an array of climate exposure data and subsequent analyses to determine historical climate trends and how the climate will likely change through the 21st Century in the Gunnison Basin. These climate data were used to assess species vulnerability with NatureServe's Climate Change Vulnerability Index (CCVI) and ecosystem vulnerability with methods developed by the Manomet Center for Conservation Sciences and Massachusetts Division of Fisheries and Wildlife (2010), TNC, and (NatureServe 2011; MCCS and MDFW 2010). Which exposure data to use and how to use them for specific assessment tools were decided by the climate data team. The high carbon dioxide emissions scenario (A2) was used because adaptation strategies for plausible large changes can help prepare for smaller changes (but not necessarily vice versa). Nonetheless, the emissions that have taken place in the years since this scenario was developed have outpaced even the highest "fossil-fuel intensive" emissions scenario (Raupach et al. 2007).

The CCVI exposure variables required temperature and precipitation data inputs available from Climate Wizard (Girvetz et al. 2009) and soil moisture deficit data inputs available from NatureServe (2011). Climate Wizard is an online climate change data distribution and map tool developed by The Nature Conservancy, the University of Washington, and the University of Southern Mississippi (see www.ClimateWizard.org). Among many other services, NatureServe provides moisture deficit and other data for download and use in the CCVI (see www.NatureServe.org). Details of how we used these data in the CCVI are provided in Appendix F of this report.

The Climate Wizard dataset used was the A2 2050 departure from historic average summer temperature Ensemble Average model, which is derived from 16 Statistically Downscaled WCRP CMIP3 Climate Projections at 12km resolution (Lawrence Livermore National Lab 2008; Maurer et al. 2007). The "Historic" data against which future departure projections are measured are from the PRISM Climate Group (Gibson et al. 2002), which is averaged over 1961-1990 at 4 km resolution and also downloadable from Climate Wizard.

The soil moisture deficit index used in the CCVI is defined with a combination of precipitation and evapotranspiration projections, and is correlated with the amount of moisture stress that plants experience during their growing season (Hamon 1961). Modeling moisture is difficult because of its dependence on both regional climate and local habitat characteristics, including temperature, precipitation, soil type, vegetation cover, and snow pack. However, approximate trends of wetting and drying may be estimated using climate data. For example, many habitats in the U.S. are predicted to experience net drying during the next 50 years, even in areas where precipitation is predicted to increase (Brooks 2009). We used the Hamon AET: PET moisture metric (Hamon 1961), as prepared by the Climate Wizard team, to assess this exposure factor for species' distribution(s) within the Gunnison Basin. The Hamon AET: PET moisture metric integrates temperature and precipitation through a ratio of actual evapotranspiration (AET) to potential evapotranspiration (PET), with consideration of total daylight hours and saturated vapor pressure. Although it is a useful measure, this metric does not include components of habitat moisture retention such as water holding capacity, effect of snow pack on water availability, and different vegetation types, all of which are challenging to incorporate at a national scale.
Ecosystem vulnerability for the Gunnison project area was determined by expert teams. Climate trends and predictions from Barsugli and Mearns (2010) informed the teams' assessments, though a variety of additional resources were used by the teams when appropriate.

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APPENDIX B: Terrestrial Ecosystem Vulnerability Assessment Summaries

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1. **Alpine (Xeric and Mesic)**
2. **Spruce-fir forests**
3. **Douglas-fir forests**
4. **Aspen forests**
5. **Bristlecone pine forests**
6. **Lodgepole pine forests**
7. **Ponderosa pine forests**
8. **Juniper woodlands**
9. **Montane sagebrush**
10. **Low-elevation sagebrush**
11. **Oak montane shrub**
12. **Montane grassland**
13. **High-elevation riparian**
14. **Mid-elevation riparian**
15. **Low-elevation riparian**
16. **Irrigated hay meadows**
17. **References**

1. ALPINE (MESIC & XERIC)

Monarch Pass with young trees encroaching into alpine
©Renee Rondeau

This system includes high-elevation dry alpine, fellfield, wet-meadow, and rock and scree communities. Alpine tundra is found at the highest elevations, usually above 11,000 feet. Here the long winters, abundant snowfall, high winds, and short summers create an environment too harsh for permanent human habitation. Vegetation in these areas is controlled by snow retention, wind desiccation, permafrost, and a short growing season.

Characteristic species for xeric: Ptarmigan, Brown-capped rosy finch, American pipits, Bighorn sheep, Pika, Marmot, and Elk.

Characteristic species for mesic: Lincoln's sparrow, White-crowned sparrow, Ptarmigan, Wilson's warbler, McGillivray's warbler, Fox sparrow, Boreal toad

Current condition	**Good** Some spots are impacted by recreation and elk
Vulnerability	**Highly vulnerable** Majority of ecosystem at risk of being eliminated (>50% loss) as a result of climate change, but unlikely to be eradicated entirely. An increase in the growing season, i.e., warmer summertime temperatures, will allow shrubs/ trees to encroach. Note that changes may happen very slowly in this cold environment, and, although we do not expect the alpine to be covered in trees and shrubs by 2050, we do expect the ecological processes needed to maintain the alpine will be severely impacted.
Confidence	**High** Literature study supports the eventual disappearance; the timeframe is uncertain, especially since growth is slow in cold environments.

Elevations of dry alpine and fell-field range from about 11,000 to 14,000 ft., with a mean of about 12,000 ft., while alpine-montane wet meadows are mapped from 8,000 to 13,000 ft. The elevational range of the xeric alpine overlaps with the upper end of the spruce-fir forest and montane grasslands. Annual average precipitation range is about 16-48 in (40-122 cm) for all types combined, with a mean of 33 in (83 cm).

In general, the concept of growing degree days (GDD) is used as an indication of the average length of the growing season (period during which temperatures are adequate for plant growth) for a particular location. The length of the growing season is particularly important for the alpine and subalpine zones. Alpine areas have the fewest growing degree days and lowest potential evapo-transpiration of any ecosystem in the Gunnison Basin. Prentice et al. (1992) found that alpine treeline is not determined by winter temperatures but rather by summer temperatures that support growth (e.g. treeline corresponds closely to areas with fewer than 350 GDD, 5ºC base).

Consequently, the distribution of alpine ecosystems is determined by the number of days that are warm enough for alpine plant growth (but not for tree growth) rather than the temperatures of the coldest months or the amount of moisture. Other alpine conditions, including lack of soil development, steep slopes, wind, and dense turf that restricts seedling establishment may also inhibit tree growth.

The IPCC has said with "high confidence" that mountain ecosystems are among the most vulnerable ecosystems to climate alteration. One example of this vulnerability is a projected reduction of areas of mountaintop tundra around the world. For instance, scientists studying the effects of climate change on Rocky Mountain National Park in Colorado, home to the largest expanse of alpine tundra in the United States outside of Alaska, projected that warming of 5.6º F (3.1º C) could cut the park's area of tundra in half and a 9 to 11º F (5-6 º C) increase could virtually eliminate it (as cited in Saunders et al. 2008).

Treeline has fluctuated in the Gunnison Basin over the past 15,000 years, The lowest treeline documented occurred about 11,000 -15,000 years ago during the last ice age when temperatures were some 3.6-9º F (2-5º C) cooler than today at a level 984-1968 ft. lower than current elevations (Fall 1997). Treeline was approximately 1,000 ft. higher than current elevations during the warmest period in the last 15,000 years when summer mean temperatures were approx. 2.9º F (1.6º C) warmer than today (Fall 1997).

The Schofield Pass SNOTEL site is about 1,000 ft. below present-day treeline. Figure 1 below shows GDD (5° C base) from 1986 and 2010 at the site ranging from 391 to 667 GDD. The data indicate an upward trend of 2º F (1.12º C) trend in a quarter of a century. Treeline predictions based on GDD (Prentice et al. 1992) indicate that the Schofield Pass site should be treed, but close to upper treeline. There are no weather stations in the alpine zone in the Gunnison Basin, so we can only interpolate from nearby weather stations. Data from Schofield Pass indicate that conditions for trees to move into alpine areas may already be present. The photograph above is from Monarch Pass and young trees can be seen in the foreground and may be evidence that trees are migrating upwards however there are no studies that support or refute this (i.e., a data gap). It would be useful to have research on the recruitment of tree seedlings at treeline and to know how this correlates with drought conditions such as occurred in 2002-2003.

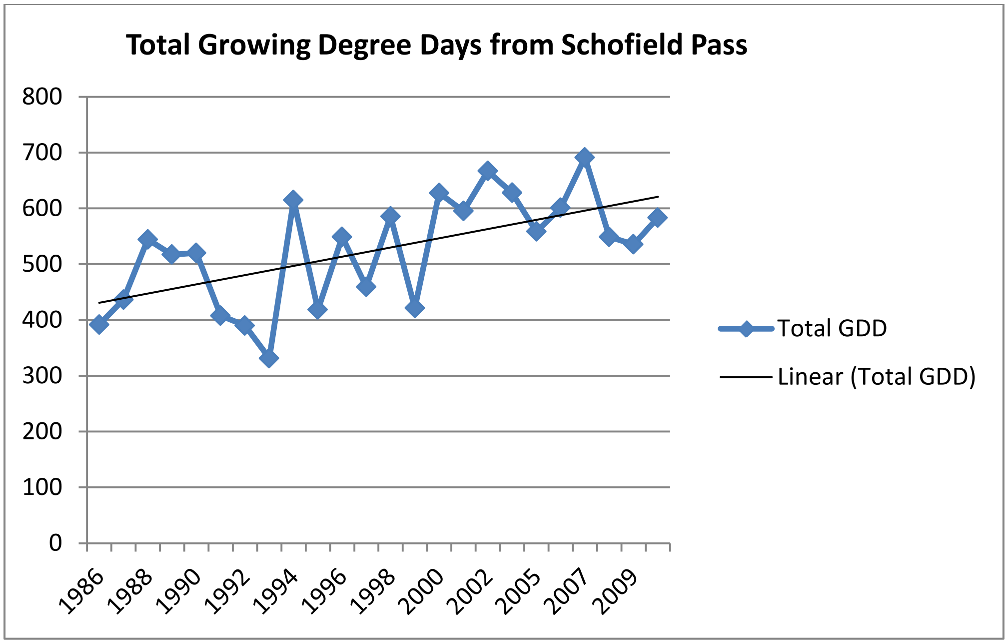


Figure 1. Total Growing Degree Days (GDD)/year for Schofield Pass SNOTEL site (USDA-NRCS 2011).

If the alpine summer mean temperatures increase 5.4 – 7.2°F (3- 4 °C) (as modeled in Barsugli and Mearns 2010) we may see treeline increase approximately 1970 ft. (600 m) higher than today. Since alpine currently occupies the 11,000-14,000 foot elevation band, an increase of nearly 2,000 ft. in treeline would leave only the 13,000-14,000 foot elevation band as alpine, and it is unlikely that species would be able to move to other alpine areas. The timing of physiognomic changes may be delayed as it takes quite a bit of time to grow trees, so although the climatic variables may exist for tree growth, the actual timing of this may be beyond 2050, there is a good chance that we will still have an appreciable area in the alpine zone at 2050, but the trend will be obvious and the climatic variables will be in place for changing the alpine meadows into a shrubland or woodland. Sagebrush currently goes to near treeline and has the potential to occupy the drier sites while trees may occupy the wetter sites. Wind and cloud cover are two variables that greatly influence alpine environments, but are poorly modeled at the scale needed to project specific alpine localities. High winds may slow the development of soil and therefore the rate of primary succession (conversion of alpine to forest).

Alpine environments are generally not susceptible to outbreaks of pest species or disease, but may have some slight vulnerability to invasive plant species such as yellow toadflax. These treeless environments are not vulnerable to fire, but could become so if trees are able to establish. Xeric alpine environments are already subject to extreme conditions, but the more mesic areas are vulnerable to drought and changes in snowmelt timing. Even under increased snowpack, warmer temperatures are likely to alter patterns of snowmelt, and may reduce available moisture. These changes are likely to result in shifts in species composition, perhaps with an increase in shrubs on xeric alpine. With warming temperatures and earlier snowmelt, elk may be able to move into alpine areas earlier, but this is not believed to be an issue.

By one calculation, the extent of western tundra has sharply declined in the 20th century. Two researchers at the National Oceanic and Atmospheric Administration reached this conclusion by studying high-altitude temperature change. Rather than examining changes in types of vegetation, which are difficult to survey on the ground and unrecorded by satellite before 1981, the researchers defined tundra by temperature, as an area where the warmest summer monthly mean temperature is between 32 and 50º F (0 -10º C). They found that only 27 percent of the area qualifying as tundra by this definition in 1901 to 1930 still qualified in 1986 to 2007. Moreover, all areas that could still be characterized as tundra were within one degree of the 50º F threshold. They concluded that temperatures are now rising so steeply that all western areas that can still be considered tundra using this standard are on the verge of disappearing.

H. Diaz and J. Eischeid, "Disappearing 'alpine tundra,' Köppen climatic type in the western United States," *Geophysical Research Letters* 34 (2007): L18707, doi:10.1029/2007GL031253, 2007.

As cited in Saunders et al. 2008.

Table 1. Summary table of vulnerability factors evaluated for alpine ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	High	Already at highest elevation in the basin.
Narrow bioclimatic envelope	Medium	There is significant natural range of variation in precipitation however temperatures are cold in the winter and cool in the summers.
Vulnerable to increased pest attacks	-	Not a concern.
Vulnerable to increased invasive species and encroachments from natives	Medium	Invasives and encroachment by trees and shrubs are likely, especially up to 13,000 feet. Increase in growing degree days will favor trees and shrubs. Yellow toadflax, oxeye daisy, knapweed are potential weeds.
Barriers to dispersal	High	No higher areas available and low probability of recolonizing other areas since they are widely scattered (isolated mountain tops separated by lower elevation habitats); alpine species don't tend to colonize after disturbance.
Vulnerable to fire	-	Not a concern.
Vulnerable to drought	Low for Mesic	Droughts at this elevation are not predicted to be too intense.
Vulnerable to timing of snowmelt	-	Snowmelt change above 8,500 ft. not expected to be dramatically different.
Vulnerable to phenologic change	Medium	Timing of pollinators and flowering may be mismatched; earlier flowering yet late frosts may decrease seed production.
Vulnerable to increased grazing/browsing	Low	Elk should be monitored.

2. SPRUCE-FIR FORESTS

Spruce-Fir at Monarch Pass

These high elevation forests form the matrix of the subalpine zone at elevations from 8,500 to 12,000 feet. They are characterized by dense stands of Engelmann spruce and subalpine fir. This is one of the few Colorado forest types that is not fire-adapted - the typical fire return frequency is around 400 years. Areas with spruce-fir forest typically receive high precipitation in the form of snowfall and frequent summer showers, but droughts can occur. During drought periods the stressed trees become susceptible to insect outbreaks, e.g., spruce beetle outbreaks, which can kill entire hillsides of trees in one summer.

Characteristic species: Boreal owl, Three-toed woodpecker, Gray jay, Pine grosbeak (breeds only in Spruce-fir)

Current condition	**Good**
Vulnerability	**Moderately Vulnerable** Extent of ecosystem at risk of being moderately impacted as a result of climate change. Increased droughts may contribute to increases in tree mortality due to spruce beetle, western balsam bark beetle and root diseases; increase in acres burned may reduce acreage; upper elevations may migrate to alpine; lower elevations may be most vulnerable.
Confidence	**Low** Uncertainty as to impact from insect outbreaks and fire events.

This forest type is widespread and dominant at elevations above 10,500, overlapping with alpine at its upper end, and with aspen and lodgepole pine at lower elevations. The overall range of annual average precipitation is comparable to that of xeric alpine (15.7-46.5 in), but the mean is lower at 25.6 in. Growing degree days and potential evapo-transpiration are more than for alpine, but fewer than for other forested types. Prentice et al. (1992) found that the extent of the upper treeline is not determined by winter temperatures but rather by summer temperatures that support growth (e.g. treeline corresponds closely to areas with fewer than 350 GDD, 5 °C base). **Spruce-fir forests are confined to areas that have more than 350 growing degree days**. Thompson et al. (2000) GDD tolerances (Table 2) and the data from Schofield SNOTEL site agree with these predictions.

In the Gunnison Basin, spruce-fir forests currently occupy cold and wet areas; warmer and drier climate conditions, as predicted by most models, could result in an upward migration of these forests into the alpine and subalpine zone, as has occurred in the past (e.g. Fall 1997 paper). Warmer summer temperatures could still be within the range of tolerance for these species, and they do not appear to be restricted to a very narrow precipitation zone (Appendix C). Furthermore, there are no obvious barriers to the gradual dispersal of seedlings into adjacent, newly suitable habitat.

In regard to forested communities in Yellowstone National Park, Bartlein et al. (1997) speculate that current spruce-fir communities may not be maintained, but may be replaced by a coniferous forest with a different species mix.

One of the most important diseases in spruce-fir forests is Armillaria root disease (Allen et al. 2010), and drought can be an important stress factor leading to its increased incidence and severity (Wargo and Harrington 1991). Although infected firs tend to die standing, spruce tend to fall while still alive (Worrall et al. 2004). If warmer and dryer conditions lead to chronic, severe root disease, the disease will lead to increased green blow down of spruce, which is a well-known trigger for outbreaks of spruce beetle (Allen et al. 2010). Spruce beetle does well in mature stands with large trees and high basal area of spruce (Schmid and Frye 1976), conditions that are common in the Gunnison Basin. During epidemics, spruce beetle has the potential to kill virtually all mature spruce across a landscape. Warmer or longer growing seasons may allow beetles to complete their life cycle in one year, rather than the normal two years, and this would make outbreaks build much faster (Berg et al. 2006; Werner and Holsten 1985). Drought stress is suspected to lead to greater susceptibility as well (Berg et al. 2006). Thus, warmer, dryer conditions can increase susceptibility to root disease, which may trigger a bark beetle epidemic that could develop more rapidly and severely than normal.

Natural fire-return intervals in these forests have been on the order of several hundred years, and the tree species are not adapted to more frequent fires (Romme et al. 2009). Under an increase in droughts and faster snowmelts we might expect an increase in forest fire frequency and extent within this zone. It is not known if spruce-fir forests will be able to regenerate under such conditions, especially in lower elevation stands, and there is a potential for a reduction in spruce-fir forests, at least in the short term. Fire severity may be just as important as frequency, e.g., the Lime Creek Burn near Molas Pass in 1879 was very severe and the spruce-fir was burned and still has not come back. However less severe fires have come back to spruce-fir fairly readily, based on statements by Alexander (1987) in publications on silviculture in spruce-fir.

The maps below (Figure 2) depict the approximate distributions of current spruce-fir cover type, recently suitable climate for spruce-fir, and projected suitable climate in 2060 based on the models of Rehfeldt et al. (2006, 2009) as calculated by J. Worrall and S. Marchetti. These models project nearly a 50% loss.

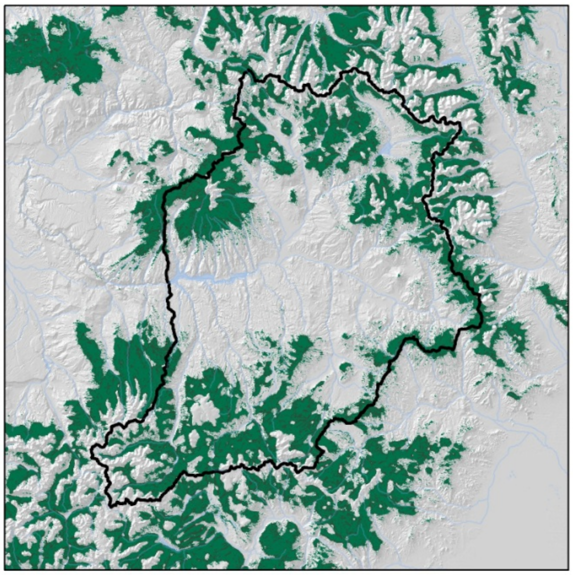
Table 2. ***Abies lasiocarpa*** **and** ***Picea engelmannii*** **tolerances for North America (Thompson et al. 2000) and data from local weather stations.**

	Mean January Temp (°C)	**Mean July Temp (°C)**	**Annual Precipitation (cm)**	**Growing Degree Days 5 (°C) base**	**Moisture Index (AET/PET)**
Species					
Abies lasiocarpa	-23 to -6	10 to 17	36 – 125	500 – 1200	0.5 – 0.98
Picea engelmannii	-19 to -5	11 to 16	44 – 120	400 – 1400	0.5 – 0.97
Ecosystem in Gunnison Basin			40-118		
Weather Stations					
Crested Butte 8,870 ft.	-11.1	13.8	62.2		
Schofield Pass 10,700 ft. (1986-2010)	-7 / -10.1	9.1/10		390-667	

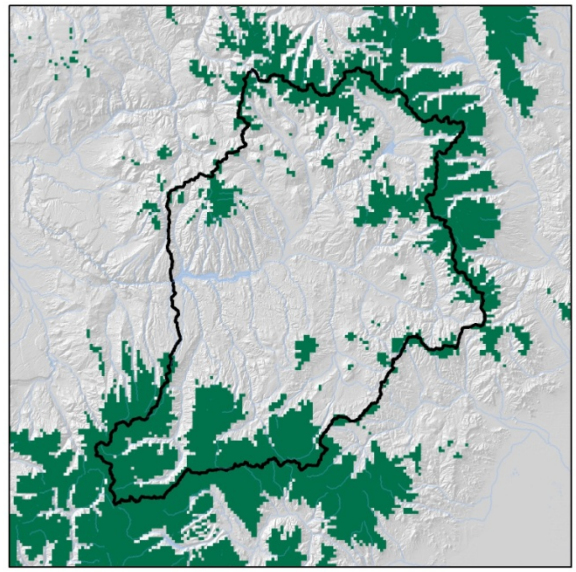
Table 3. Summary table of vulnerability factors evaluated for spruce-fir forest ecosystems.

Vulnerability Factor	**Rating**	**Comments**
Restricted to high elevation	-	Not a concern. Currently found from 8,300-13,300 ft. (mean 10,670 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	-	Not a concern.
Vulnerable to increased pest attacks	High	Interaction with drought likely to increase vulnerability.
Vulnerable to increased invasive species and encroachments from natives	Low or unknown	Lodgepole pine and other trees may move in; resulting in a shift to mixed conifer especially within the given time frame.
Barriers to dispersal	-	None known.
Vulnerable to fire	Medium	This system will likely shift if the fire return interval becomes shorter and fires increase in acreage. Under dryer conditions and with earlier snow melt, lower elevation fires may move into spruce-fir. It is unclear if these forests can come back as spruce-fir after disturbance. They will probably shift to grasslands and other forest types.
Vulnerable to drought	Medium	More drying expected; we don't understand how regeneration is affected by drought.
Vulnerable to timing of snowmelt	Medium	May be vulnerable at the end of summer; if earlier melt results in lower moisture availability at end of growing season.
Vulnerable to phenologic change	-	Not a concern.
Vulnerable to increased grazing/browsing	-	Not a concern.

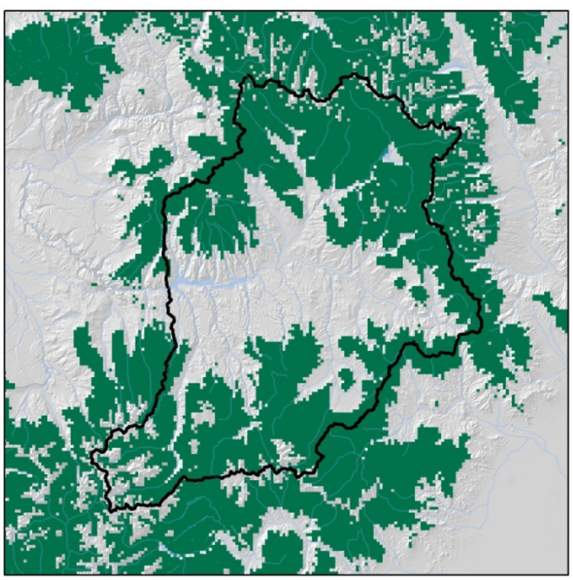
Figure 2. Distribution of current Spruce-fir forests, recently suitable climate and projected 2060 suitable climate.



2007 actual in SWReGap



2060 suitable – Rehfeldt model



1961-1990 suitable – Rehfeldt model

3. DOUGLAS-FIR FORESTS

Douglas-fir forest © Renee Rondeau

Douglas-fir forests occupy areas from 7,600 to 10,500 feet in elevation, often on steep north-facing slopes; however some stands occupy warmer and less steep slopes. A diverse shrub and herbaceous layer are common in good condition stands however fire suppression and grazing/browsing has increased tree density and decreased understory diversity. A variety of tree species may co-occur with the dominant Douglas-fir including blue spruce, lodgepole pine, aspen, and ponderosa pine. At the upper elevations lodgepole pine, aspen, and spruce-fir ecosystems may be adjacent to the Douglas-fir ecosystem while ponderosa pine may be adjacent at the lower elevations. Insect outbreaks have devastated whole watersheds of Douglas-fir in the Gunnison Basin (Johnston et al. 2001). The Douglas-fir bark beetle and other bark beetles are capable of outbreaks.

Characteristic species: Ruby-crowned kinglet, Hermit thrush, Hammond's flycatcher, Williamson's sapsucker, Yellow-rumped warbler, Pine siskin, Red-breasted nuthatch, Townsend's solitaire, Western tanager, Brown creeper, Cassin's finch, Red crossbill, Olive-sided flycatcher, Mountain chickadee, Juncos, snowshoe hare, lynx, pine marten.

Current condition	**Fair**
Vulnerability	**Highly Vulnerable**
Confidence	**Low**

For the purposes of this report, Johnston et al. (2001) blue spruce uplands ecological type has been lumped with the Douglas-fir type, primarily due to mapping resolution, thus the following description and vulnerability includes both ecological types. Both types occur in cold-air drainages and deep-rain shadow climates.

Douglas-fir forests and upland blue spruce forests in the Gunnison Basin are generally in mid-elevations and on steep cool slopes; good condition stands Douglas-fir have a dense shrub cover that may consist of serviceberry, bitterbrush, or buffaloberry. Arizona fescue, Thurber fescue, elk sedge, and kinnikinnick may dominate the ground cover.

Since most stands are already limited to the coolest aspects (north-facing) in the montane zone they may be highly vulnerable to increased warming. The maps below (Figure 3) depict the approximate distributions of current Douglas-fir cover type, recently suitable climate for spruce-fir, and projected suitable climate in 2060 based on the models of Rehfeldt et al. (2006, 2009) as calculated by J. Worrall and S. Marchetti. These models predict nearly a 100% loss by 2060.

Fires are a natural part of this system with a fire frequency between 50 to 200 years (Fitzhugh et al. 1987). Following a stand replacing fire, aspen and lodgepole pine are the most likely successors. Fire suppression has increased the risk of stand replacing fires and an increase in droughts could make this system vulnerable. Stands with a mixed tree component may fare better than stands dominated by Douglas-fir.

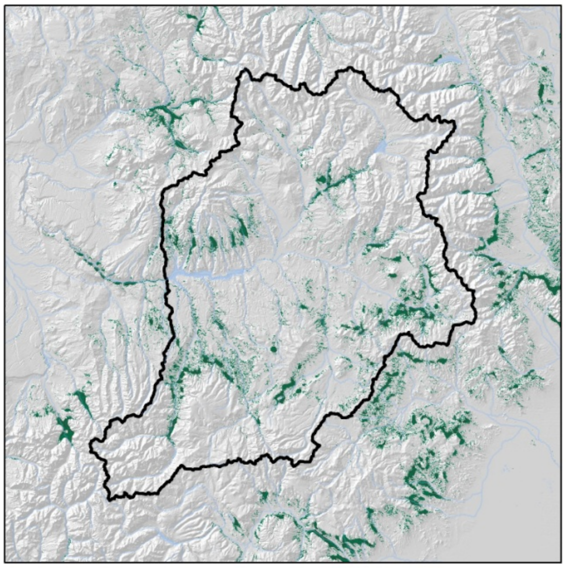
Table 4. *Pseudotsuga menziesii* tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	**Mean July Temp (°C)**	**Annual Precipitation (cm)**	**Growing Degree Days 5 °C base**	**Moisture Index (AET/PET)**
Species					
Pseudotsuga menziesii	-12 to 5	11 to 20	41 - 162	500 - 2500	0.51 - 0.96
Ecosystem in Gunnison Basin			33-81		
Local weather station					
Lake City 8,890 ft.	-9.1	15.7	35.5	2519	

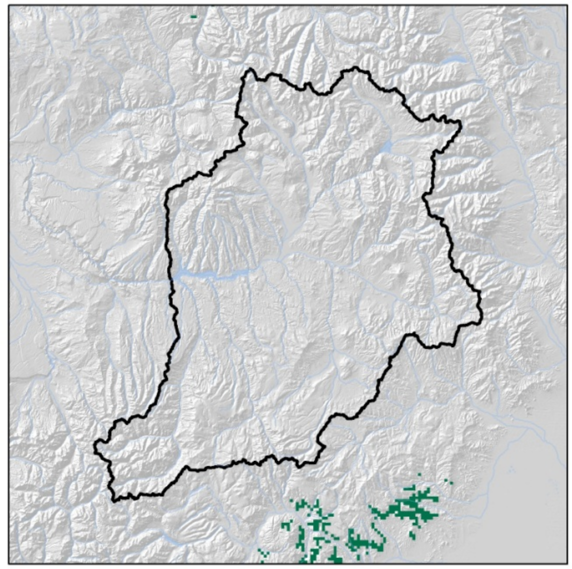
Table 5. Summary table of vulnerability factors evaluated for Douglas fir forest ecosystems.

Vulnerability Factor	**Rating**	**Comments**
Restricted to high elevation	-	Not a concern. Currently found from 7,500 – 11,950 ft. (mean 9,260 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	Medium	Mostly restricted to north-facing slopes
Vulnerable to increased pest attacks	High	Outbreaks have been observed to devastate stands
Vulnerable to increased invasive species and encroachments from natives	-	Unknown
Barriers to dispersal	-	None known: may be able to move into areas currently dominated by lodgepole or lower elevation spruce-fir.
Vulnerable to fire	High	Fire suppression has increased risk to most stands; vulnerability should be similar to spruce-fir
Vulnerable to drought	High	Most stands are currently in moist areas.
Vulnerable to timing of snowmelt	High	Earlier snowmelt would negatively impact growth
Vulnerable to phenologic change	-	Not a concern.
Vulnerable to increased grazing/browsing	Medium	Shrubs and herbaceous layers are prone to grazing pressures

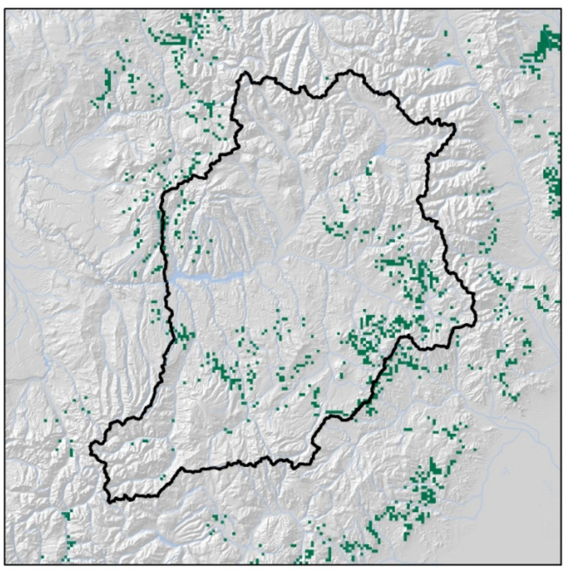
Figure 3. Distribution of current Douglas-fir, recently suitable climate and projected 2060 suitable climate.



2007 actual in SWReGap



2060 suitable – Rehfeldt model



1961-1990 suitable – Rehfeldt model

4. ASPEN FORESTS

Aspen forest near Ohio Creek

These are upland forests and woodlands dominated by quaking aspen, or forests of mixed aspen and conifer, ranging in elevation from about 8,500 to 11,200 feet. They usually occur as a mosaic of many plant associations and may be surrounded by a diverse array of other systems, including grasslands, wetlands, coniferous forests, etc. Aspen forests are one of our most species-rich ecosystems. Most of the plant and animal species that inhabit aspen forests are relatively abundant and not of significant conservation concern.

Characteristic species: Warbling vireo, Red-naped sapsucker, House wren

Current condition	**Fair to Good** Depends on elevation
Vulnerability	**Moderately Vulnerable**
Confidence	**Low**

In the Gunnison Basin, aspen forests are generally found below lodgepole pine or spruce-fir forests, and are often transitional to montane sagebrush shrublands or grasslands. Elevations broadly overlap the range of lodgepole and bristlecone, and the lower portion of spruce-fir. Annual precipitation range is similar to that of spruce-fir, at 15.7-42.9 in (40-109 cm), and with a somewhat drier mean of 22.8 in (58 cm). Mean precipitation is similar to that of bristlecone and lodgepole. Growing degree days and PET are higher than for the previous forested types, and are almost exactly the same as for montane grassland in the area.

Aspen is closely tied to moisture availability and in the Rocky Mountains stands generally occur where annual precipitation is greater than 14.9 in (38 cm) per year (Morelli and Carr 2011) and summer temperatures are moderate. Aspen is rated as very intolerant to drought (Niinemets and Valladares 2006). It is highly susceptible to diseases when temperatures get high, e.g., Front Range gardeners often complain about how hard it is to keep aspens healthy even when water is ample. Sudden aspen decline (SAD) has received quite a bit of attention in recent years, and is sometimes referred to as aspen dieback. SAD caused substantial mortality in over 17% of the aspen cover type from 2004-2009, and evidence strongly points to the 2002 drought as an inciting factor (Rehfeldt et al. 2009; Worrall et al. 2010). SAD was most severe where moisture conditions are marginal: at low elevations, on south and southwest slopes, and on exposed, upper slope positions (Worrall et al. 2008, 2010). Some stands may undergo thinning and then recover, while the most severely affected stands had virtually complete mortality. Although aspens can become established in higher elevation areas of the Gunnison Basin, possibly moving into areas where lodgepole pine resides, there is much uncertainty about the future distribution of this species. Morelli and Carr (2011) found that there is an unpredictable future for aspen in the West, where increased drought, ozone, and insect outbreaks will vie with carbon dioxide fertilization and warmer soils, resulting in unknown cumulative effects.

The maps below (Fig. 4) depict the approximate distributions of current aspen cover type, recently suitable climate for aspen, and projected suitable climate in 2060 based on the models of Rehfeldt et al. (2006, 2009) as calculated by J. Worrall and S. Marchetti. These models project about 10% loss of suitable aspen habitat by 2060; as the montane climate continues to warm aspen presence in the basin may be fairly limited by 2100. This is much more favorable than in most areas. For Colorado and southern Wyoming, models project 50% less area with suitable climate in the 2060s. Increasing drought with climate change is believed to be the primary vulnerability of this ecosystem, and the effects of drought are likely to interact with other vulnerabilities such as outbreaks of pests and disease, snowmelt timing, and ungulate herbivory. One study modeled that aspen in the Canadian boreal will increase productivity for the next 200 years, acting as a large carbon sink. However, prolonged (6-year) droughts would eventually cause severe dieback (Grant et al. 2006). Therefore, some researchers stress that the long-term effects of elevated atmospheric carbon dioxide on aspen will be complex and difficult to predict (Hogg 2001, Lindroth et al. 2001).

Climate change may induce indirect effects on aspen productivity via increased frequency of vulnerability to pathogens and herbivores, which interact with environmental stress to cause tree mortality (Morelli and Carr 2011; Marchetti et al. in press). Heavy grazing by elk in combination with drought appears to be leading to decline in some areas (Morelli and Carr 2011). Stress from grazing could be mitigated by management actions. Canker infections and forest tent caterpillar outbreaks are tightly associated with drier and warmer conditions (Cryer and Murray 1992, Johnston 2001, Logan 2008, Hogg et al. 2001). There may be extreme barriers to aspen migration even over very short distances if regeneration from seed is infrequent (Coop, pers. communication).

The interaction of climate change with natural disturbance may also affect the future distribution of aspen. Although aspen is not fire tolerant, it is likely to establish in forests that have burned or been reduced in cover due to insect damage, if other conditions are suitable. The strong response of aspen regeneration in the area of the 2002 Missionary Ridge fire near Durango may give an indication of the future of aspen forests in southwest Colorado.

Table 6. *Populus tremuloides* tolerances for North America (Thompson et al. 2000) and data from local weather station.

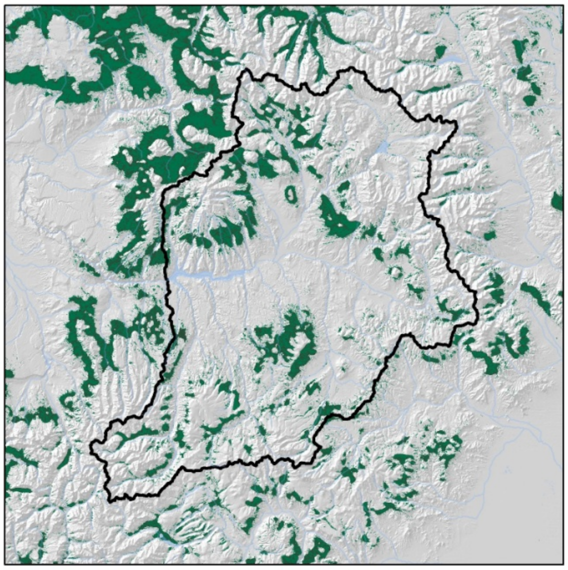
	Mean January Temp (°C)	**Mean July Temp (°C)**	**Annual Precipitation (cm)**	**Growing Degree Days 5 °C base**	**Moisture Index (AET/PET)**
Species					
Populus tremuloides	-28 to -6	13 to 21	33 - 106	600 - 2100	0.50 - 0.99

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 5 °C base	Moisture Index (AET/PET)
Ecosystem in Gunnison Basin			40-109		
Local weather station					
Crested Butte 8,870 ft.	-11.1	13.8	62.2	1852	

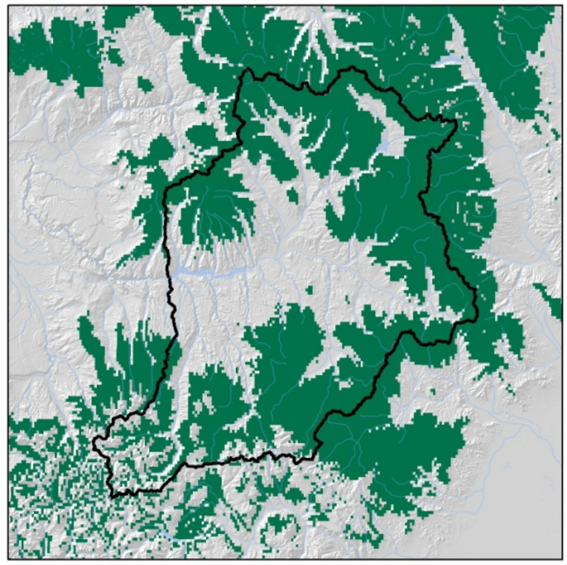
Table 7. Summary table of vulnerability factors evaluated for aspen forest ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	-	Not a concern. Currently found from 8,500-11,200 ft. (mean 9,900 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	Low	Current Gunnison Basin precipitation range is 40-109 cm; annual precipitation exceeds annual evapotranspiration.
Vulnerable to increased pest attacks	Medium	Droughts increase vulnerability to pest and pathogen outbreaks.
Vulnerable to increased invasive species and encroachments from natives	Low	Although climate change may increase invasive species, it is not believed to be a significant factor
Barriers to dispersal	Medium	Asexual reproduction is more prevalent than sexual reproduction.
Vulnerable to fire	Low	Aspens have been found to be 200 times less likely to burn than spruce-fir stands (Bigler et al. 2005). Aspen will burn with more frequent fire, but generally can re-sprout.
Vulnerable to drought	Medium	The 2002 drought killed some aspen stems; a prolonged drought could reduce aspen stands; those stands that are currently in the wetter zones will probably fare better. Aspens may adapt by moving up in elevation.
Vulnerable to timing of snowmelt	Low	
Vulnerable to phenologic change	Low	May start growing earlier in the season but this should not be a problem and could have a positive influence.
Vulnerable to increased grazing/browsing	High	Intense grazing/browsing is known to degrade aspen stands. If a stand is stressed from climate, especially drought, then the stand will be less resistant to grazing/browsing pressures

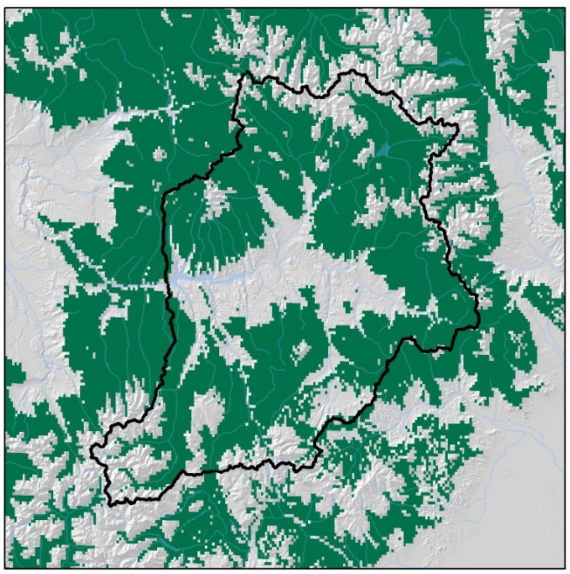
Figure 4. Distribution of current Aspen forests, recently suitable climate and projected 2060 suitable climate.



2007 actual in SWReGap



2060 suitable – Rehfeldt model



1961-1990 suitable – Rehfeldt model

5. BRISTLECONE PINE FORESTS

Bristlecone pine © Renee Rondeau

Bristlecone pine forests and woodlands are typically found on steep, south-facing slopes from 9,000 to 12,000 ft throughout the Rocky Mountains on dry, rocky ridges and slopes. Although they can be found near upper treeline above the matrix spruce-fir forest, they also occurs at lower elevations. Sites are typically harsh, exposed to desiccating winds with rocky substrates and a short growing season that limit plant growth. Higher elevation occurrences are found well into the subalpine - alpine transition on wind-blasted, mostly south to west-facing slopes and exposed ridges.

Characteristic species:

Current condition	**Good**
Vulnerability	**Highly vulnerable**
Confidence	**Low**
	Uncertainty of impacts from drought

Bristlecone pine forest is a minor type in the Gunnison Basin, accounting for fewer than 7,000 acres in the upper Cochetopa Creek drainage. The elevational range is similar to that of spruce-fir forest, however bristlecone pine appears to occur on generally drier sites, with an average annual precipitation range of 18.1 – 31.1 in (46 -79 cm) and a mean of 21.2 in (54 cm). Growing degree days and potential evapo-transpiration are higher than for spruce fir, and are virtually the same as for lodgepole pine.

Bristlecone pine trees are vulnerable to the recent rapid spread of white pine blister rust, and climate conditions are expected to continue to favor the spread of this pathogen (Coop and Schoettle 2009). Due to the longevity and low recruitment rate of these trees, the prevalence of resistance to white pine blister rust cannot increase at a rate comparable to expected climate change (Schoettle and Sniezko 2007). Bristlecone pine trees are also vulnerable to outbreaks of the mountain pine beetle (*Dendroctonus ponderosae*), especially in mixed stands with other five-needle pine species (Gibson et al. 2008). The importance of fire in this ecosystem is variable, and is most important on productive sites where infrequent, stand-replacing fires reduce competition from other species and create conditions where bristlecone seedlings can establish. However, regeneration after fire is very slow (Coop and Schoettle 2009). A natural fire regime may enhance regeneration, potentially increasing the genetic variation available for natural selection for resistance to white pine blister rust (Schoettle and Sniezko 2007). This very long-lived species probably has the ability to weather some intense climate changes, but is likely to be slow to adapt to rapid change. Bristlecone pine is endemic to the Southern Rocky Mountain Ecoregional and it is not widespread within this region and it is worthy of monitoring.

Table 8. *Pinus aristata* tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 5 °C base	Moisture Index (AET/PET)
Pinus aristata	-11.6 to -8	8 to 13	39 – 74	200 - 800	0.57 - 0.96
Bristlecone representation in Gunnison			46-79		

Table 9. Summary table of vulnerability factors evaluated for bristlecone forest ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	-	Currently found from 9,050-12,000 ft. (mean 10,300 ft.) in Gunnison Basin. Higher habitat exists, but bristlecone may be less able to compete for new, higher habitat.
Narrow bioclimatic envelope	Low	Competitive exclusion more likely than narrow tolerance.
Vulnerable to increased pest attacks	High	Vulnerable to white pine blister rust spread, mountain pine beetle.
Vulnerable to increased invasive species and encroachments from natives	High	Not a good competitor therefore it is vulnerable to encroachment
Barriers to dispersal	High	Seeds do not disperse far from source, unless cached by birds. Regeneration in harsh conditions is enhanced by protection provided by microtopographic structure.
Vulnerable to fire	Low	Tends to grow in rocky areas that don't support fire.
Vulnerable to drought	??	Uncertain.
Vulnerable to timing of snowmelt	Low	
Vulnerable to phenologic change	-	Not a concern.
Vulnerable to increased grazing/browsing	-	Not a concern.

6. LODGEPOLE PINE FORESTS

Lodgepole forest above Tellurium Creek

In the Gunnison Basin, the lodgepole pine forests are located on the eastern side of the basin between 8,800-11,000 ft. in elevation (mean of 10,000 ft.) and occur on gentle to steep slopes. Stands may be pure lodgepole pine, or mixed with other conifer species. Most forests in this ecosystem developed following fires. Following stand-replacing fires, lodgepole pine rapidly colonizes and develops into dense, even-aged stands. Shrub and groundcover layers are often sparse in lodgepole pine forests, and diversity of plant species is low, perhaps as a result of the uniform age and dense canopy of many stands. Most lodgepole stands outside of the Gunnison Basin are experiencing widespread damage from a severe outbreak of mountain pine beetle, a native species whose periodic outbreaks are part of the natural cycle that maintains mountain forests; however this is not currently a factor in Gunnison Basin.

Characteristic species: "not a very productive site for birds or mammals, however dead trees will attract woodpeckers" (from Amy Seglund).

Current condition	**Good**
Vulnerability	**Moderately vulnerable**
Confidence	**Medium**

Lodgepole pine is characteristic of the eastern portion of the Gunnison Basin, in the upper drainages of the Taylor River, Tomichi Creek and Quartz Creek. For the most part, lodgepole pine reaches its southern distribution in the Gunnison Basin, although it goes slightly farther south on the East Slope. Elevation ranges overlaps with the aspen ecosystem. Precipitation is similar to, but intermediate with bristlecone and aspen, with a range of 41-89 cm and a mean of 57. Growing degree days and PET are essentially the same as for bristlecone pine, but less than aspen.

Lodgepole pine is a northern species that does exceptionally well in very cold climates and can tolerate a wide range of annual precipitation patterns, from fairly dry to fairly wet. In fact, there are currently more areas of apparently suitable climate conditions in the Gunnison Basin than are occupied by these forests. **Summer (warm months) temperature appears to be driving lodgepole pine distribution, and it seems to have a fairly narrow bioclimatic envelope in the Gunnison Basin (Fig 4).** Disturbance history and competition play large roles in lodgepole pine distribution. Currently stands are in the drier and colder parts of the Gunnison Basin (the eastern half). As precipitation patterns get drier there is some potential that lodgepole pine could move into other portions of the Gunnison Basin, although it is not likely to occupy areas warmer than the current habitat. The maps below (Figure 5) depict the approximate distributions of current lodgepole cover type, recently suitable climate for lodgepole, and projected suitable climate in 2060 based on the models of Rehfeldt et al. (2006, 2009) as calculated by J. Worrall and S. Marchetti. The wider temperature range tolerance of spruce enables it to dominate the warmer upper montane zones, excluding lodgepole. To the south of the Gunnison Basin, white fir (*Abies concolor*) appears to take the place of lodgepole pine in coniferous forests of similar elevations. There is a zone in the southern part of the Gunnison Basin where neither lodgepole pine nor white fir occurs. This could be due to extreme events keeping both of these species out (e.g., it periodically gets too warm for lodgepole but it is often too cold for white fir). White fir is able to tolerate warmer temperatures than lodgepole pine; under warmer conditions it may be able to move into the basin.

Lodgepole pine often competes with either spruce or aspen and fires are an important component for lodgepole pine forest regeneration. This fire-adapted species has the potential to move into areas where spruce-fir forests burn. Although invasives are not a factor, lodgepole forests are vulnerable to the insect outbreaks that appear to increase with warmer, drier, drought-prone climates. If conditions develop that prohibit the regeneration of lodgepole forests, they are likely to disappear from the Gunnison Basin.

Table 10. *Pinus contorta* tolerances for North America (Thompson et al. 2000) and data from local weather station.

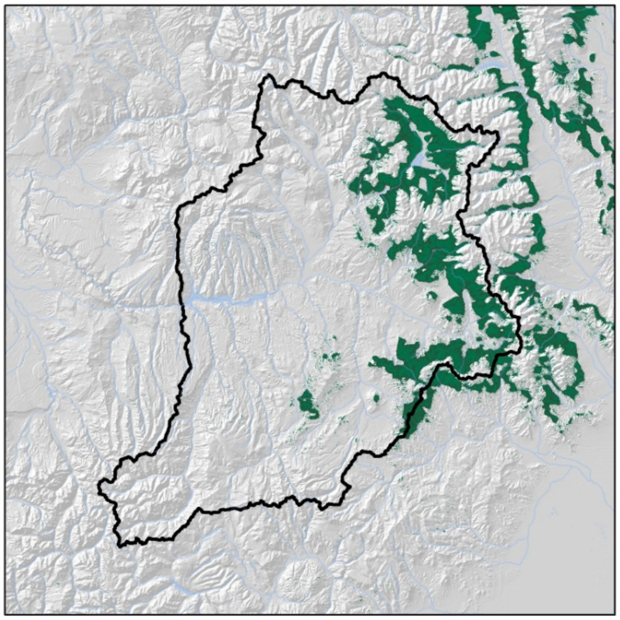
	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 5 °C base	Moisture Index (AET/PET)
Species					
Pinus contorta	-22 to -2	11 to 16	42 – 167	500 - 1300	0.55 - 0.99
Ecosystem in Gunnison Basin			41-89		
Local weather station					
Taylor Park 9210 feet	-13.7	13.2	41.4	1659	

Table 11. Summary table of vulnerability factors evaluated for lodgepole pine forest ecosystems.

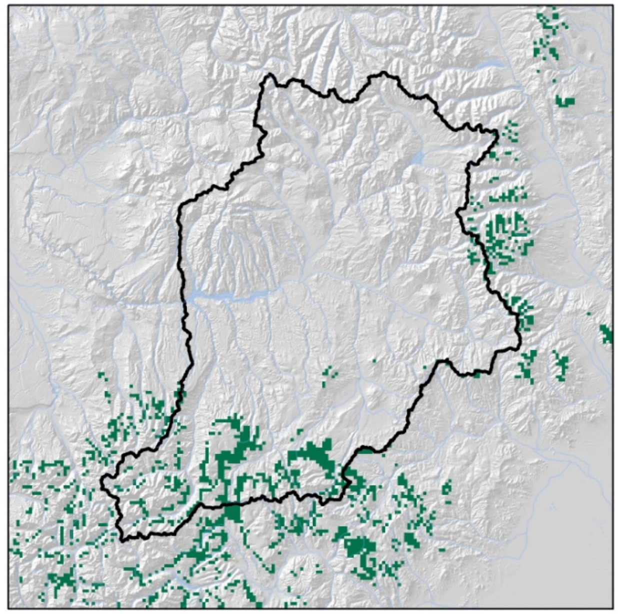
Vulnerability Factor	Rating	Comments
Restricted to high elevation	Low	Currently found from 8,170-11,740 ft. (mean 10,170 ft.) in Gunnison Basin. May be able to regenerate in place or move into area currently occupied by spruce-fir.
Narrow bioclimatic envelope	Low	Although at southern edge of range, unknown if this is because of competition or climate. An increase in July temperatures may inhibit regeneration.
Vulnerable to increased pest attacks	High	Vulnerable, although conditions in current habitat

Vulnerability Factor	Rating	Comments
		may be too cold, predicted warmer temperatures may increase vulnerability.
Vulnerable to increased invasive species and encroachments from natives	Low	Likely to be encroached on by aspen and mixed conifer.
Barriers to dispersal	-	None known.
Vulnerable to fire	High	Drought may increase fire frequency
Vulnerable to drought	Medium	Insect outbreaks occur with drought
Vulnerable to timing of snowmelt	-	Not a concern.
Vulnerable to phenologic change	-	Not a concern.
Vulnerable to increased grazing/browsing	-	Not a concern.

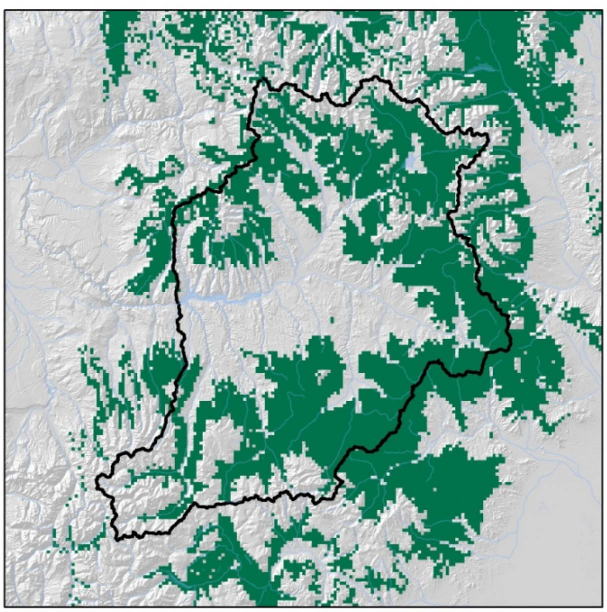
Figure 5. Distribution of current lodgepole pine forests, recently suitable climate and projected 2060 suitable climate.



2007 actual in SWReGap



2060 suitable – Rehfeldt model



1961-1990 suitable – Rehfeldt model

7. PONDEROSA PINE FORESTS

Ponderosa pine stand near Lake City

In Colorado these matrix-forming woodlands occur at the lower treeline transition between grassland or shrubland and the more mesic coniferous forests above. Healthy ponderosa pine forests often consist of open and park-like stands of mature trees, with an understory of predominantly fire-tolerant grasses and forbs. Frequent, low-intensity ground fires are typical in these forests. In stands where the natural fire regime still occurs, shrubs, understory trees and downed logs are uncommon. A century of human development and fire exclusion has resulted in a higher density of ponderosa pine trees in many areas.

Characteristic species: Pygmy nuthatch, Western bluebird

Current condition	**Good**
Vulnerability	**Moderate increase or vulnerability**
Confidence	**Low**

Ponderosa woodlands occur primarily in the southern portion of the area on the mesas and ridges above the middle reaches of the Cebolla Creek and Lake Fork of the Gunnison drainages, where they are at elevations similar to those of mixed conifer forest and montane sagebrush. These are generally small stands in a mosaic of sagebrush shrublands. Elevations are generally between 8,000 and 10,000 ft., with a mean of about 9,150 ft. Annual precipitation is similar to that for mixed conifer and montane sagebrush, with a range of 14.1 – 22.8 in (36-58 cm) and a mean of 17.3 in (44 cm). Growing degree days and PET are just slightly higher than mixed conifer, but are lower than montane sagebrush.

Ponderosa pine is able to tolerate fairly warm temperatures as long as there is enough moisture, especially in the growing season. This species occurs under much drier conditions elsewhere, and is not expected to be vulnerable to drought in the Gunnison Basin. Extant stands are maintained in conditions that promote low-intensity fires. Although climate change may alter fire regimes slightly by affecting the community structure, fire is not expected to have a severe impact in the future for these stands, and may actually be beneficial in some areas. These forests are susceptible to cheatgrass invasion in the understory, as well as outbreaks of mountain pine beetle and mistletoe infestations, all of which may be exacerbated by increased drought. Impacts of native grazers or domestic livestock could also alter understory structure and composition. Ponderosa pine woodlands may be able to expand upwards in elevation or remain in the same vicinity if precipitation doesn't drastically change.

Stands in the Gunnison Basin are small and well managed, which has so far mitigated the threats from climate change. Continued management will likely be needed to maintain the current distribution and condition of ponderosa pine in the area, if desired. Although seeds are typically not dispersed very far, ponderosa pine is often present in mixed conifer stands; these areas may provide a seed bank for regeneration or a shift to ponderosa pine. Optimal germination and establishment conditions occur when temperatures are above 50°F and monthly precipitation is greater than 1 inch (Shepperd and Battaglia 2002). The work of Brown and Wu (2005) suggests that coincident conditions of sufficient moisture and fewer fires are important for widespread recruitment episodes of ponderosa pine; such conditions may become less likely under future climate scenarios.

Table 12. *Pinus ponderosa* tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	**Mean July Temp (°C)**	**Annual Precipitation (cm)**	**Growing Degree Days 5 °C base**	**Moisture Index (AET/PET)**
Species					
Pinus ponderosa	-9 to 7	14 to 23	33 – 108	800 - 3900	0.44 - 0.88
Ecosystem in Gunnison Basin			36-58		
Local weather station					
Lake City 8,890 ft.	-9.1	15.7	35.5	2519	

Table 13. Summary table of vulnerability factors evaluated for ponderosa forest ecosystems.

Vulnerability Factor	**Rating**	**Comments**
Restricted to high elevation	-	Not a concern. Currently found from 7,550-11,000 ft. (mean 9,150 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	-	
Vulnerable to increased pest attacks	Low	
Vulnerable to increased invasive species and encroachments from natives	Medium	Weed encroachment is a concern and can change fire frequency.
Barriers to dispersal	-	
Vulnerable to fire	Low	Open stands are savanna-like and unlikely to have large crown fires typical of denser stands. Fire behavior will likely change if there is an increase of shrubs. Dense stands could support high intensity crown fires that could negatively impact this system.
Vulnerable to drought	Low	
Vulnerable to timing of snowmelt	-	Snowmelt changes will be greater at elevations where ponderosa are found than at higher elevations.
Vulnerable to phenologic change	-	
Vulnerable to increased grazing/browsing	Low to Medium	

8. JUNIPER WOODLANDS

Juniper woodlands © Renee Rondeau

This is the characteristic system of Colorado's western mesas and valleys; however it occupies relatively few acres in the Gunnison basin and ranges in elevation from 7,400 and 9,500 ft., with a mean of about 8,200 ft. on dry mountains and foothills. Rocky Mountain juniper forms the canopy. These woodlands often occur in a mosaic with other systems, including sagebrush and oak shrubland. The understory is highly variable, and may be shrubby, grassy, sparsely vegetated, or rocky. Severe climatic events occurring during the growing season, such as frosts and drought, are thought to limit the distribution of juniper systems to the relatively narrow altitudinal belts that they occupy.

Characteristic species: Plumbeous vireo, Gray flycatcher, Black-throated gray warbler, Bushtit, Pinyon jay are good indicators for juniper woodlands but there are few records of these breeding in the Basin.

Current condition	**Good**
Vulnerability	**Presumed stable to Moderate increase**
	May expand within the Gunnison Basin into stressed low sagebrush
Confidence	**Low**

A very minor woodland type in the Basin, found in small patches along the lower reaches of tributaries to the Gunnison (now draining into Blue Mesa Reservoir); juniper woodlands are the warmest and driest of the tree-dominated systems in the area. Annual precipitation is 12.2 – 20.8 in (31-53 cm), with a mean of 16.5 in (42 cm), most similar to ponderosa. Growing degree days and PET are the highest for any tree-dominated type, and are generally similar to those for oak-shrub.

Although currently poorly represented in the Gunnison Basin, this type may expand into adjacent sagebrush systems with climate change. Stands are currently very scattered and dominated by juniper. Paleobotanical studies indicate that pinyon pine was present in the basin in the past. Future expansion will likely be determined by winter precipitation patterns, and it is expected that pinyon may be able to return to stands in the area, with a resulting expansion of these woodlands into adjacent sagebrush shrublands.

Table 14. *Pinus edulis, Juniperus osteosperma*, and *J. scopulorum* tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 5 °C base	Moisture Index (AET/PET)
Species					
Pinus edulis	-7 to 2	18 to 24	22 - 46	1500 - 2900	0.29 – 0.68
Juniperus osteosperma	-8 to 1	17 to 24	18 - 50	1300 - 2800	0.26 – 0.65
Juniperus scopulorum	-12 to -2	11 to 21	31 - 92	500 - 2100	0.42 – 0.93
Ecosystem in Gunnison Basin			31-53		
Local weather station					
Blue Mesa Dam 7,620 ft.	-10	17.7	24.6		

Table 15. Summary table of vulnerability factors evaluated for juniper woodland ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	-	Not a concern. Currently found from 7,400- 9,700 ft. (mean 8,200 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	-	
Vulnerable to increased pest attacks	Low	
Vulnerable to increased invasive species and encroachments from natives	Low	Cheatgrass could impact vulnerability of Juniper woodlands to fire.
Barriers to dispersal	Low	
Vulnerable to fire	Low	Juniper only occupies approximately 4000 acres in the basin and most stands are young trees encroaching into sagebrush. Stands are sparse. Fire behavior depends on understory species.
Vulnerable to drought	Low	
Vulnerable to timing of snowmelt	-	
Vulnerable to phenologic change	-	
Vulnerable to increased grazing/browsing	??	

9. MONTANE SAGEBRUSH SHRUB

Montane sagebrush near Flat Top

Montane sagebrush stands in Gunnison Basin have a very large elevation range (7,500 to 11,000 ft.), typically on deep-soiled to stony flats, ridges, nearly flat ridgetops, and mountain slopes. Colorado occurrences are found primarily on the West Slope, often in proximity to lower elevation big sagebrush shrublands. These montane shrublands have a fairly dense canopy usually dominated by *Artemisia tridentata* ssp. *vaseyana;* other shrubs include bitterbrush, rabbitbrush, and snowberry and a well-vegetated understory of grasses, sedges, and forbs, e.g., pine needle-grass, muttongrass, paintbrush, and phlox.

Characteristic species: Brewer's sparrow, Sage sparrow, Sage thrasher, Green-tailed towhee, Gunnison Sage-grouse, Gunnison's prairie dog, Pronghorn

Current condition	**Good**
Vulnerability	**Moderate increase** Ability to expand into areas that are currently forested, especially aspen
Confidence	**Medium**

Montane sagebrush shrublands are widespread and dominant in the Gunnison Basin. Annual precipitation is 12.2 – 29.5 in (31-75 cm) and a mean of 17.7 in (45 cm), similar to oak-mixed shrub. However, habitats are cooler, with growing degree days and PET less than for oak-mixed shrublands.

These sagebrush shrublands of higher elevations are considered likely to expand with changing climate conditions, this conclusion is supported by results of Harte's meadow-warming experiments at RMBL (Harte et al. 1995). There are no apparent barriers to the expansion of these shrublands into adjacent forested ecosystems, especially aspen, and the effects of drought and the timing of snowmelt are not expected to have a restraining effect on the growth of the shrublands. Elk grazing may have a more significant impact on sagebrush under earlier snowmelt than is currently the case. Montane sagebrush communities are characterized by an understory of forbs and perennial bunch grasses (Arizona fescue at lower elevations, Thurber fescue at higher elevations) that is thought to be more resistant to invasive species than that of lower elevation sagebrush shrublands. There is a moderate potential for invasion by knapweed species, oxeye daisy, leafy spurge, and yellow toadflax under changing climatic conditions, and a potential for changing fire dynamics to affect the ecosystem. There is no information on the vulnerability of this ecosystem to insect or disease outbreak. Certain species may respond more negatively, e.g., bitterbrush is less drought tolerant than sagebrush (B. Johnston, pers. communication).

Although sagebrush can handle rather dry conditions and fairly cool temperatures it is not fire adapted, however, this system might move into forested areas that burn up and dieback from drought (including disease dieback). This system has the potential to move into what is currently alpine if the upper elevations warm yet the precipitation is fairly dry. Compared to other sagebrush taxa, mountain big sage has a greater potential to increase in density, depending on moisture availability (Rosentreter 2005).

Table 16. *Artemisia tridentata* tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 0 °C base	Moisture Index (PET)
Species					
Artemisia tridentata	-9.7 to -0.7	15 to 23	20 – 55	1000 - 2500	0.27 – 0.64
Ecosystem in Gunnison Basin			31-75		
Local weather stations					
Taylor Park 9210 ft.	-13.7	13.2	41.4	1659	
Cochetopa Creek 8,000 ft.	-11.1	16.2	28.2		

Table 17. Summary table of vulnerability factors evaluated for montane sagebrush ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	-	Not a concern. Currently found from 7,480-11,300 ft. (mean 8,950 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	-	
Vulnerable to increased pest attacks	-	
Vulnerable to increased invasive species and encroachments from natives	Medium	
Barriers to dispersal	-	
Vulnerable to fire	Low	
Vulnerable to drought	Low	Montane sage did exceptionally well during the 2002 drought (Austin & Johnston, pers. comm.)
Vulnerable to timing of snowmelt	-	
Vulnerable to phenologic change	-	
Vulnerable to increased grazing/browsing	Low	

10. LOW-ELEVATION SAGEBRUSH SHRUBLANDS (BIG SAGEBRUSH SHRUB)

Low-elevation sagebrush near South Beaver Creek

Big sagebrush shrublands are characterized by stands of taller sagebrush species with a significant herbaceous understory, and are generally found at elevations from 7,500 to 9,000 feet. The presence of the taller sagebrush species distinguishes these shrublands from the often adjacent montane sagebrush shrublands. Big sagebrush shrublands are typically found in broad basins between mountain ranges, on plains and foothills.

Characteristic species: Brewer's sparrow, Sage sparrow, Sage thrasher, Green-tailed towhee, Gunnison sage grouse, Gunnison's prairie dogs, Pronghorn

Current condition	**Fair to Good**
Vulnerability	**Presumed stable**
Confidence	**Low**

These shrublands dominate the lower elevations around the Gunnison River and Blue Mesa Reservoir where they generally occur below adjacent montane sagebrush shrublands. Several species of sagebrush occur, depending on slope, aspect and soil type, e.g., big sagebrush, Wyoming big sagebrush, and black sagebrush (Johnston et al. 2001). These are the driest ecosystems of the basin, with annual precipitation of 11.8 – 18.8 in (30-48 cm) and a mean of 14.1 in (36 cm). Precipitation is more-or-less evenly distributed throughout the year. Low-elevation sagebrush shrublands are also the warmest, with growing degree days and PET higher than for other systems.

Because these are shrublands of lower elevations, they are not expected to be limited by a requirement for cooler, high elevation habitat. Stands in the Gunnison Basin are already established in cooler, drier habitats than are typical for this type outside the area. There are no apparent barriers to dispersal for these plant communities, although there is some question of whether adjacent pinyon and juniper communities will replace the big sagebrush stands if winter temperatures warm sufficiently. These stands may also be somewhat vulnerable to changes in phenology. Increased fire frequency would negatively impact sagebrush systems as sagebrush has a high mortality rate when burned.

Although big sagebrush and understory cool season grass species are often found in areas that are much drier than the Gunnison Basin, there is uncertainty about whether they are vulnerable to drought. In general, big sagebrush communities are highly drought-tolerant; during the extremely dry year of 2002 stands in the basin experienced high levels of dieback, especially for old or decadent individuals. In subsequent years, however, there was a high level of regeneration of sage and grasses. Soil moisture data from the past few decades (BLM) should be incorporated into this evaluation, but it is reported that seeps, springs, and ponds in the area appear to be drying, and snowmelt is becoming earlier. Depending on the frequency of drought in the future, community composition may shift gradually, with the potential loss of some cool-season grasses, and the increase of non-native species. Stress from frequent drought conditions could potentially produce a threshold effect under which the entire community is converted to another type, although this seems less likely since it appears to tolerate warmer, drier conditions further west.

Low-elevation shrublands in the Gunnison Basin typically support a grassy understory where forbs are ephemeral. Dominant species include pine needle grass, and short stature grasses such as squirreltail, muttongrass, and others. Understory composition is highly vulnerable to change from increased presence of invasive species such as cheatgrass, knapweed species, whitetop, perennial pepperweed and others, and such changes may also alter fire dynamics. As the climate changes, cheatgrass appears to be adapting to higher elevations and is likely to increase its presence in these shrublands, gaining a foothold in disturbed areas and then moving into the rocky sites with poor soil development that are characteristic of many examples of this ecosystem (Goodrich 2005). The increased coverage of cheatgrass is also likely to increase the incidence of fire in this system, although a decrease in fall and spring moisture could reduce cheatgrass coverage.

Although sagebrush can handle rather dry conditions and fairly cool temperatures it is not fire adapted. It may be able to move into adjacent forested areas that are cleared by fire or drought/disease die-off. It is possible that these shrublands could even move into what is currently alpine if the upper elevations warm yet the precipitation is fairly low. Earlier snowmelt may also contribute to a change understory species composition, or affect the recruitment of seedlings if soil moisture availability does not correspond well with other requirements. The effects of insect and disease outbreaks are not believed to be an issue for this ecosystem. Sagebrush communities may be affected by increased pressure from elk and deer under earlier snowmelt conditions, but in general this is not likely to be one of the most significant impacts.

Table 18. *Artemisia tridentata* tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 0 °C base	Moisture Index (PET)
Species					
Artemisia tridentata	-9.7 to -0.7	15 to 23	20 – 55	1000 - 2500	0.27 – 0.64
Ecosystem in Gunnison Basin			30-48		
Local weather stations					
Sapinero	-7.7	15.2	28.2		
Blue Mesa Dam 7,620 ft.	-10	17.7	24.6		
Gunnison 7,630	-12.7	16.4	25	2567	

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 0 °C base	Moisture Index (PET)
Sapinero	-7.7	15.2	28.2		

Table 19. Summary table of vulnerability factors evaluated for low-elevation sagebrush ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	-	Currently found from 7,450-9,000 ft. (mean 8,200 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	Low	
Vulnerable to increased pest attacks	-	
Vulnerable to increased invasive species and encroachments from natives	High	Cheatgrass continues to increase in abundance and distribution at low elevations and predicted climate changes will enhance this trend
Barriers to dispersal	-	
Vulnerable to fire	High	As invasive species such as cheatgrass increase, fire frequency and severity may increase (Goodrich 2005). In addition, increased drought frequency may favor fire conditions.
Vulnerable to drought	Low	
Vulnerable to timing of snowmelt	Low?	
Vulnerable to phenologic change	Low?	
Vulnerable to increased grazing/browsing	Low	

11. OAK MOUNTAIN SHRUB

Oak mountain shrub ©Renee Rondeau

These montane shrublands generally occur at elevations from about 7,500 to 10,000 feet, and are often situated above juniper woodlands. Gambel oak is typically dominant, but very often mixed with other montane shrubs such as serviceberry, mountain mahogany, antelope bitterbrush, big sagebrush, chokecherry, and snowberry. These shrublands may form dense thickets, or occur as open shrublands with an herbaceous understory. Although this is a shrub-dominated system, some trees may be present. Fire typically plays an important role in this system, causing shrub die-back in some areas, promoting stump sprouting of the shrubs in other areas, and controlling the invasion of trees into the shrubland system.

Characteristic species: Spotted towhee, Virginia warblers, Green-tailed towhee, Blue-gray gnatcatcher

Current condition	**Fair to Good** Depending on location within the basin
Vulnerability	**Moderate increase** May expand into low sagebrush
Confidence	**Medium**

Oak-mixed mountain shrublands are a minor ecosystem type in the Gunnison Basin, occurring in scattered patches in most drainages in the western part of the area. These are primarily communities of serviceberry or Gambel oak, with oak dominant in stands at the western boundary of the basin (sometimes in a mosaic with sagebrush), oak and mountain shrub on ridges, and serviceberry with mahogany at higher elevations. Annual precipitation is 12.9 – 30.3 in (33-77 cm), with a mean of 17.3 in (44cm). Growing degree days and PET are similar to those of pinyon-juniper.

In general, stands of these deciduous shrublands in the Gunnison Basin are not thought to be highly vulnerable to climate change. The fact that oak dieback in 2002 seldom resulted in the death of an individual tree indicates that the species is somewhat drought tolerant. Persistent frost-kill of growing tips may eventually affect its survival. As a clonal species, Gambel oak is very hardy once established, however there are areas of dead oak in the basin for which the cause of mortality is currently unknown. More information is needed to determine if these die-off areas (e.g. Black Canyon National Park) are the result of a pest or disease outbreak that may be exacerbated by climate change (or a combination of drought and oak borer). In areas in the western portion of the basin oak stands are vulnerable to increased prevalence of invasive species such as cheatgrass and knapweeds. Currently there are few invasives in the stands dominated by serviceberry and mahogany. These shrublands are highly fire tolerant, but may be impacted by higher elk winter use, especially in serviceberry and mahogany stands. It is possible for this system to move up in elevation, especially if fires open up some of the adjacent forested ecosystems.

Table 20. *Quercus gambelii, Amelanchier utahensis*, and *Juniperus scopulorum* tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 5 °C base	Moisture Index (AET/PET)
Species					
Quercus gambelii	-9 to 2	14 to 24	24 – 65	800 – 2800	0.32 – 0.83
Amelanchier utahensis	-12 to 0	13 to 23	27 – 68	700 – 2400	0.37 – 0.84
Juniperus scopulorum	-12 to -2	11 to 21	31 – 92	500 – 2100	0.42 – 0.93
Ecosystem in Gunnison Basin			33-77		

Table 21. Summary table of vulnerability factors evaluated for oak mountain shrub ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	-	Not a concern. Currently found from 7,500-10,600 ft. (mean 8,300 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	Low	
Vulnerable to increased pest attacks	Low	
Vulnerable to increased invasive species and encroachments from natives	Medium	
Barriers to dispersal	-	
Vulnerable to fire	-	
Vulnerable to drought	Low	
Vulnerable to timing of snowmelt	-	
Vulnerable to phenologic change	Low	
Vulnerable to increased grazing/browsing	High	

12. MONTANE GRASSLAND

Montane Grasslands ©Jonathan Coop

Montane grasslands in Colorado typically occur from 7,500 to 12,000 feet and are intermixed with matrix stands of spruce-fir, lodgepole, ponderosa pine, and aspen forests. Lower elevation montane grasslands are more xeric, while upper montane or subalpine grasslands are more mesic. Typical species include fescue, muhly, oatgrass, and others. Trees and shrubs are generally sparse or absent, but occasional individuals from the surrounding communities may occur. Precipitation patterns differ between the east and west sides of the Continental Divide. In general, these grasslands experience long winters and short growing seasons.
Characteristic species: Western meadowlark, Vesper sparrow, Gunnison's prairie dog, Burrowing owls

Current condition	**Good**
Vulnerability	**Presumed stable**
Confidence	**Low**

Montane grasslands in the Gunnison Basin have a wide elevational range and are found throughout the basin with the largest occurrence in Cochetopa Park. Annual precipitation range is also large, with a range of 12.9 – 40.9 in (33-104 cm) and a mean of 22.8 in (58 cm), similar to aspen. Growing degree days and PET are also essentially the same as those of aspen.

The extent, distribution, and composition of montane grasslands in the Gunnison basin include a variety of grasses, e.g., Indian ricegrass, needle-and-thread, Arizona fescue, Thurber fescue, Idaho fescue, and oatgrass. Occurrences of these grasslands may frequently represent ecosystems already significantly altered from their pre-settlement condition. In general, Arizona fescue is more common at lower elevations, and Thurber fescue grasslands are characteristic of higher, subalpine areas with deep soils. Grasslands on Red Mountain appear to be stable, while areas along Beaver Creek represent bottomlands and wet meadows. There is speculation that some areas such as Cochetopa Park would, in the absence of heavy grazing disturbance, transition to a sagebrush shrubland. Distribution of grassland in the Gunnison Basin is likely related to shallow soils and wind prone areas and is most susceptible to invasion by sagebrush. Increased fire frequency would act to kill shrubs and maintain or increase the current acreages of montane grassland.

Table 22. Montane grassland tolerances for North America (Thompson et al. 2000) and data from local weather station.

	Mean January Temp (°C)	Mean July Temp (°C)	Annual Precipitation (cm)	Growing Degree Days 0 °C base	Moisture Index (PET)
Montane grassland in Gunnison Basin			33-104		
Local weather station					
Taylor Park 9210 ft.	-13.7	13.2	41.4		

Table 23. Summary table of vulnerability factors evaluated for montane grassland ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to high elevation	Low	Not a concern. Currently found from 7,500-12,450 ft. (mean 9,900 ft.) in Gunnison Basin.
Narrow bioclimatic envelope	Low	
Vulnerable to increased pest attacks	Low	
Vulnerable to increased invasive species and encroachments from natives	Medium	
Barriers to dispersal	Low	
Vulnerable to fire	Low	Vulnerability may depend on soil type; however are generally fire adapted.
Vulnerable to drought	Low	These areas were stable during 2002 drought.
Vulnerable to timing of snowmelt	-	
Vulnerable to phenologic change	Low	
Vulnerable to increased grazing/browsing	Medium	

Riparian Ecosystems

The following is the scoring system used for the overall vulnerability of the Gunnison Basin riparian ecosystems.

Definitions

Vulnerability Rating	Meaning
High	Overall loss of system is expected to be > 50% or ecological process is expected to be severely impacted, e.g., flood frequency occurs 50% less than current flooding regime
Moderate	Overall loss of system is expected to be between 10 and 50% or condition within system is expected to decline; e.g., up to 50% of riparian areas is infested by non-native species
Low	0 to 10% loss of area and condition of system remains stable

Summary of Vulnerability Scores

Ecosystem	Vulnerability Score	Confidence
High-elevation riparian	Low to Moderately Vulnerable	Medium
Mid-elevation riparian	Moderately Vulnerable	Medium
Low Elevation riparian	Highly Vulnerable	Low
Irrigated hay meadows	Moderately Vulnerable	Medium

13. HIGH-ELEVATION RIPARIAN ECOSYSTEM

Alpine riparian (CNHP photo)

High-elevation riparian ecosystem includes coldwater riparian habitats within the alpine zone. These systems are generally found above 11,000 feet and are best characterized as being treeless riparian areas surrounded by treeless uplands. They are often dominated by short willows, e.g., *Salix planifolia* and *S. wolfii* with sedges, e.g., *Carex aquatilis* and forbs, e.g., *Caltha leptosepala*. Some areas will be strictly herbaceous in cover without a willow over story. The dominant process is abundant snowfall, cold and long winters and cool short summers. Snow depth and retention are important for maintaining the water table.

Characteristic species: Ptarmigan and coldwater invertebrates (e.g. stoneflies, mayflies, caddisflies; Canton and Chadwick 1983).

Current condition	**Good**
Vulnerability	**Moderate Vulnerability** The lower elevations of this system, i.e., near treeline are vulnerable to encroachment by trees and shrubs from the subalpine zone thus changing the structural and species composition, while the upper elevations may be less vulnerable
Confidence	**Medium** High uncertainty in future moisture regime and unknown rate of change to vegetation as temperature warms.

Most high-elevation streams are in the Gunnison National Forest and many are within Wilderness Areas. Although subject to grazing, fragmentation by roads, and recreation, these stream systems are generally in good condition and have little to no direct anthropogenic alterations.

Although most models show that higher elevations will experience relatively greater temperature increases, current temperatures are typically cold limiting for many species above 9,000 feet including pathogens and non-native species. Increased temperatures are expected to lead to earlier and higher-magnitude peak flows, but sensitivity of high elevation ecosystem function to these hydrologic changes is expected to be low, in part because the geomorphology of many of these streams is bedrock constrained.

Table 24. Summary table of vulnerability factors evaluated for high-elevation riparian ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to High Elevation/or edge of southern range	High	found at the highest elevation
Vulnerable to increased pest attacks	Low	cool environment not vulnerable to pest attacks
Vulnerable to increased invasive species and encroachments from natives	Medium	low elevation band of this system may be vulnerable to structural composition change with relationship to trees or shrubs moving in
Vulnerable to dispersal rate	Low	Dominant plants are primarily wind dispersed and pollinated and therefore not vulnerable
Vulnerable to fire	Low	Fire frequency is none to low
Vulnerable to drought	Low	Current predictions/models are not predicting large changes; 2002 and 2004 drought did not show a strong negative response; willows and sedges are acclimatized to high fluctuations in moisture level but even in drought they will stay moister than uplands
Vulnerable to timing of snowmelt	Low	Timing of snowmelt is not an important driver; we don't expect much more than a 10-15% decrease in annual precipitation and this system should tolerate this range
Vulnerable to phenologic change	Low	Most plants can tolerate wide range of temperatures in spring and early warming or late frosts should not have a significant negative impact
Vulnerable to increased grazing/browsing	Medium	Browsing/grazing pressures could increase if elk spend more time in this system
Current loss and stress	Low	There is very little loss of riparian systems in the alpine
Decrease in Base Flows	Low	Late summer flows may be altered but our confidence is low as there is a high degree of uncertainty in the models

14. MID-ELEVATION RIPARIAN ECOSYSTEM

Lake Fork of the Gunnison
© Renee Rondeau

Mid-elevation riparian ecosystem is generally located within the 9,000-11,000 foot elevation band and is generally characterized as dominated by trees or shrubs. *Picea pungens* and other conifers are the typical trees; willows vary from mid-sized to tall willows, e.g., *Salix drummondii*, and *Salix brachycarpa*. Cottonwoods do not occur in this ecosystem. Stream channels vary from narrow and steep to wide and meandering. The surrounding upland vegetation varies but is often coniferous dominated. Examples of this system include East River valley below Gothic and Lake Fork of the Gunnison.

Characteristic species: include Brook trout, cutthroat trout, beaver (*Castor canadensis*), and coldwater invertebrates (e.g. stoneflies, mayflies, caddisflies; Canton and Chadwick 1983). These streams provide habitat for boreal toad (*Bufo boreas boreas*), an at-risk species.

Current condition	**Good**
Vulnerability	**Moderately Vulnerable** Numerous factors ranked as medium vulnerability and predicted loss of area due to low-elevation cottonwoods moving into zone as temperatures warm.
Confidence	**Medium** High uncertainty in future moisture regime and unknown rate of change to vegetation as temperature warms.

Most mid-elevation riparian areas in the Upper Gunnison Basin are in good condition. Alexander and Brown (2009) found that, overall, the riparian condition of Coal Creek, its tributaries and lakes is in relatively healthy condition. However, pockets of high and even extreme degradation do exist. For example, the eroded slope on the north side of Kebler Pass Road east of the Mt. Emmons Mine access road contributes noticeable sediment to Coal Creek (Alexander and Brown 2009). Several mid-elevation streams are impacted by heavy metals, specifically Coal Creek (cadmium and zinc), Henson Creek and Oh-Be-Joyful Creek (cadmium, copper, lead and zinc). Because many of these streams are on public land, expansion of roads and other development is unlikely. However, some are affected by sedimentation, unstable stream banks, and other factors, with some prominent stresses in highly localized area. The Slate River is impacted by high levels of cadmium and zinc (Colorado Department of Public Health and Environment 2008; Bembenek 2001).

Table 24. Summary table of vulnerability factors evaluated for mid-elevation riparian ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to High Elevation/or edge of southern range	low	This ecosystem is below the high-elevation riparian ecosystem and therefore not restricted
Vulnerable to increased pest attacks	Low	Even though conifers may be more susceptible to insects the moisture stress in riparian is less than uplands therefore the riparian trees are presumed to be less susceptible
Vulnerable to increased invasive species and encroachments from natives	Medium	Could have an overall drying of this system, especially with additional water draws and therefore upland species on edges could move in and change species composition
Vulnerable to dispersal rate	Low	Dispersal barriers are not considered as an important factor
Vulnerable to fire	Low	Although fire frequency is presumed to increase in the adjacent uplands the riparian system is less likely to burn; if they do burn, trees are more susceptible to mortality than the willows. Therefore willows would benefit so that species composition may change but the ecosystem is not presumed to be severely impacted
Vulnerable to drought	Medium	Could have an overall drying of this system, especially with additional draws and therefore upland species on edges could move in and change species composition
Vulnerable to timing of snowmelt	Medium	Snowmelt related processes are important due to timing of flooding events; willow establishment is somewhat sensitive to flooding events and may be impacted however willows can also reproduce asexually; beavers are an important species in this system and assist with mitigating flooding events
Vulnerable to phenologic change	Low	Most plants can tolerate wide range of temperatures in spring and early warming or late frosts should not have a significant negative impact
Vulnerable to increased grazing/browsing	Medium	Pressure will increase as low elevations become less productive
Current loss and stress	Moderate	Condition has been altered from grazing pressures; loss of habitat from development & water diversion
Decrease in base flows	Moderate	With snow coming off sooner and more quickly there will be lower flows in the late summer causing moisture stress on riparian vegetation

15. LOW-ELEVATION RIPARIAN ECOSYSTEM

Taylor River © Dee Malone

Low-elevation riparian ecosystem is generally located below 9,000 feet and is generally characterized as the area where cottonwood trees can thrive. Although cottonwood trees are a good indicator of this system it is not unusual to find willow dominated riparian areas with few to no cottonwood trees. The understory ranges from sedges and grasses to bare ground. This system is below the mid-elevation riparian system. Stream channels vary from narrow and steep to wide and meandering. The surrounding upland vegetation varies from aspen and conifers to sagebrush dominated. Examples of this system include Gunnison River, Taylor River below Taylor Park Reservoir and Slate River below Crested Butte.

Characteristic species: Gunnison sage grouse utilize some sites during brood rearing season. Other animals include leopard frog, river otter, beaver, bald eagle, great blue heron, and sandhill cranes.

Current condition	**Fair**
Vulnerability	**Moderately Vulnerable** Although this system is more vulnerable than mid elevation it still has an overall moderate vulnerability rank because we don't anticipate a 50% loss due to climate factors. It also has the ability to migrate upstream. The lower elevations of this system are highly vulnerable to invasive species.
Confidence	**Medium** High uncertainty in future moisture regime and unknown rate of change to vegetation as temperature warms.

Current condition of rivers ranges from fair to good, depending on the component being considered. For riparian areas, BioEnvirons (2010) found that 87% of linear miles of the mainstem of the Gunnison River between Almont and McCabe's Bridge (~3 miles below the town of Gunnison) are in proper functioning condition however, 50% of riparian forest habitat in this reach has been lost. This riparian system has been utilized by humans more intensively than any of the other riparian systems. This is the system that was converted into irrigated hay meadows.

This system is more vulnerable to invasive species than any other riparian system. Flooding events are amplified in this system and the native species have evolved with high variability in flooding events. The change in snowmelt and flooding events may impact this system. Cottonwood trees may be vulnerable to prolonged drought. Drier summers will be conducive to invasive species. Although tamarisk and Russian olive are not present in this system there is potential for these species to move in with warming temperatures.

Table 25. Summary table of vulnerability factors evaluated for low-elevation riparian ecosystems.

Vulnerability Factor	Rating	Comments
Restricted to High Elevation/or edge of southern range	low	
Vulnerable to increased pest attacks	low	not aware of any vulnerability
Vulnerable to increased invasive species and encroachments from natives	High	herbaceous understory is already altered and with warming additional species will be in the mix, e.g., tamarisk and Russian olive
Vulnerable to dispersal rate	low	
Vulnerable to fire	Low	Narrowleaf cottonwoods can regenerate from underground shoots as can willows
Vulnerable to drought	Moderate	some inherent resistance; lowered water table for an extended period of time will stress cottonwoods and willows; droughts can create more bare grounds resulting in weedy herbaceous strata
Vulnerable to timing of snowmelt	High	The disturbance and related geomorphologic processes are critical to maintaining riparian areas dominated by cottonwood
Vulnerable to phenologic change	Moderate	Could be a timing mismatch between seed generation and flood events
Vulnerable to increased grazing/browsing	Moderate	Increased pressures on riparian areas as uplands get drier
Current loss and stress	High	50% loss documented by Alexander. Many converted to managed hay meadows
Decrease in base flows	Moderate	We anticipate a 10% decrease in total annual flow and less moisture and more stress and decrease in total riparian areas

16. IRRIGATED HAY MEADOWS

Ohio Creek © Renee Rondeau

*Irrigated hay meadows are*s generally located below 9,000 feet and is generally characterized as wide flood plains with meandering streams. This system is extremely important to the ranching industry and has been altered to provide hay meadows for the cattle industry. Alterations include removal and management of willows and cottonwoods, and construction of ditches to irrigate the meadows. Although some cottonwood trees and willows are present, the system is dominated by grasses and sedges. The surrounding uplands are often dominated by sagebrush. Examples of this system include Tomichi Creek and Ohio Creek. This system is in the same zone as the low-elevation riparian ecosystem.

Characteristic species: Gunnison sage grouse utilize some sites during brood rearing season. Other animals include leopard frog, river otter, beaver, bald eagle, great blue heron, and sandhill cranes.

Current condition	**Good** In terms of "naturalness", this system is highly altered. However, the condition given the management intent of these is good throughout much of the basin where hay meadows occur,
Vulnerability	**Moderately Vulnerable** Although this system is vulnerable to prolonged droughts, if adequate water is available, it may be possible to mitigate some drought impacts. However the need to utilize this system is even more important during a drought as the adjacent uplands will have lower productivity. Predicted earlier runoff and faster snowmelt may impact irrigation practices.
Confidence	**Medium** High uncertainty in future moisture regime and unknown rate of change to vegetation as temperature warms.

Hay meadows form a long-standing and important traditional use of riparian areas in the Upper Gunnison Basin. These areas consist largely of native grasses and sedges, yet they represent substantial alteration from natural conditions. Under natural conditions, more woody vegetation would be present along streams and throughout the riparian area. There would likely also be more beaver present, creating more variable habitats throughout the riparian areas. However, the extent of moist habitats may be greater under irrigated conditions because water is diverted from streams and spread widely across both riparian and adjacent (former) upland areas.

The primary vulnerability to hay meadows—and thus to the viability of ranching in the Gunnison Basin—is to decreases in water that can be diverted to hay meadows. This decrease in water availability can result from several factors, including increased crop irrigation requirements that result in lower return flows, low later-summer flows resulting from earlier snowmelt, or more frequent downstream senior "calls." Less water availability results in less irrigation and less crop production. These conditions could be more intense during extreme drought conditions.

Another potential vulnerability to hay meadows results from a general lack of woody vegetation along stream banks in many irrigated meadows. The herbaceous vegetation that is present has less capacity to provide stream bank stability in comparison to woody vegetation. Although snowmelt is expected, on average, to be smaller than recent decades (Markstrom et al. *in press*), there may also be more extreme events, including extreme flooding events. Under extreme flooding events, stream banks with poor stability become highly vulnerable to unnaturally fast erosion.

Table 26. Summary table of vulnerability factors evaluated for irrigated hay meadows.

Vulnerability Factor	Rating	Comments
Restricted to High Elevation/or edge of southern range	Low	Hay meadows are generally low in the basin. They could move higher as temperatures warm.
Vulnerable to increased pest attacks	Low	not aware of any vulnerability
Vulnerable to increased invasive species and encroachments from natives	Medium	Invasive plant species that require warmer temperatures could become a problem.
Vulnerable to dispersal rate	Low	
Vulnerable to fire	Low	Not applicable
Vulnerable to drought	Medium	Lowered water table for an extended period of time will stress meadows even with the irrigation potential; irrigation potential could be substantially reduced.
Vulnerable to timing of snowmelt	High	An earlier and possibly faster runoff will reduce irrigation potential, especially in the late summer.
Vulnerable to phenologic change	Low	
Vulnerable to increased grazing/browsing	Moderate	Increased pressures on riparian areas as uplands get drier
Current loss and stress	Low	
Decrease in base flows	High	We anticipate a 10-25% decrease in total annual flow in rivers and therefore this will probably translate to less water for irrigation. Lower water availability will be compounded by increased consumptive use by crops, thus smaller return flows.

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APPENDIX C: General Information for Ecosystems of the Gunnison Basin

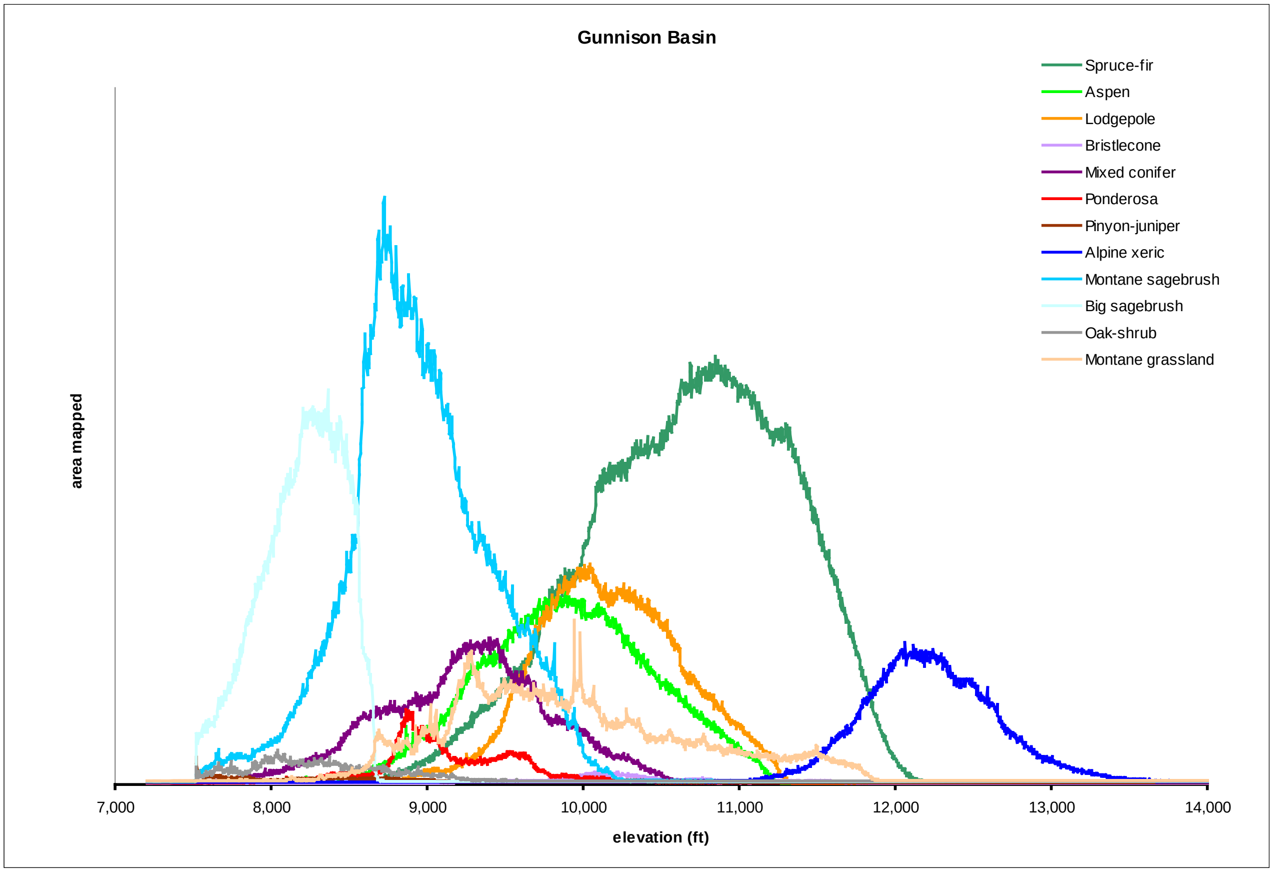

Figure 1. Elevation

	Elevation (ft.)		
Ecosystem	**Min**	**Max**	**Mean**
Alpine	8,035	14,085	11,944
Spruce-fir	8,278	13,304	10,672
Bristlecone	9,049	12,031	10,344
Lodgepole	8,176	11,742	10,170
Montane grassland	7,546	12,467	9,910
Aspen	7,664	12,310	9,900
Mixed Conifer	7,516	11,949	9,258
Ponderosa	7,546	11,079	9,145
Montane sagebrush	7,480	11,303	8,948
Oak Mixed shrub	7,523	10,633	8,307
Pinyon-juniper	7,434	9,695	8,209
Big sagebrush	7,447	9,016	8,202

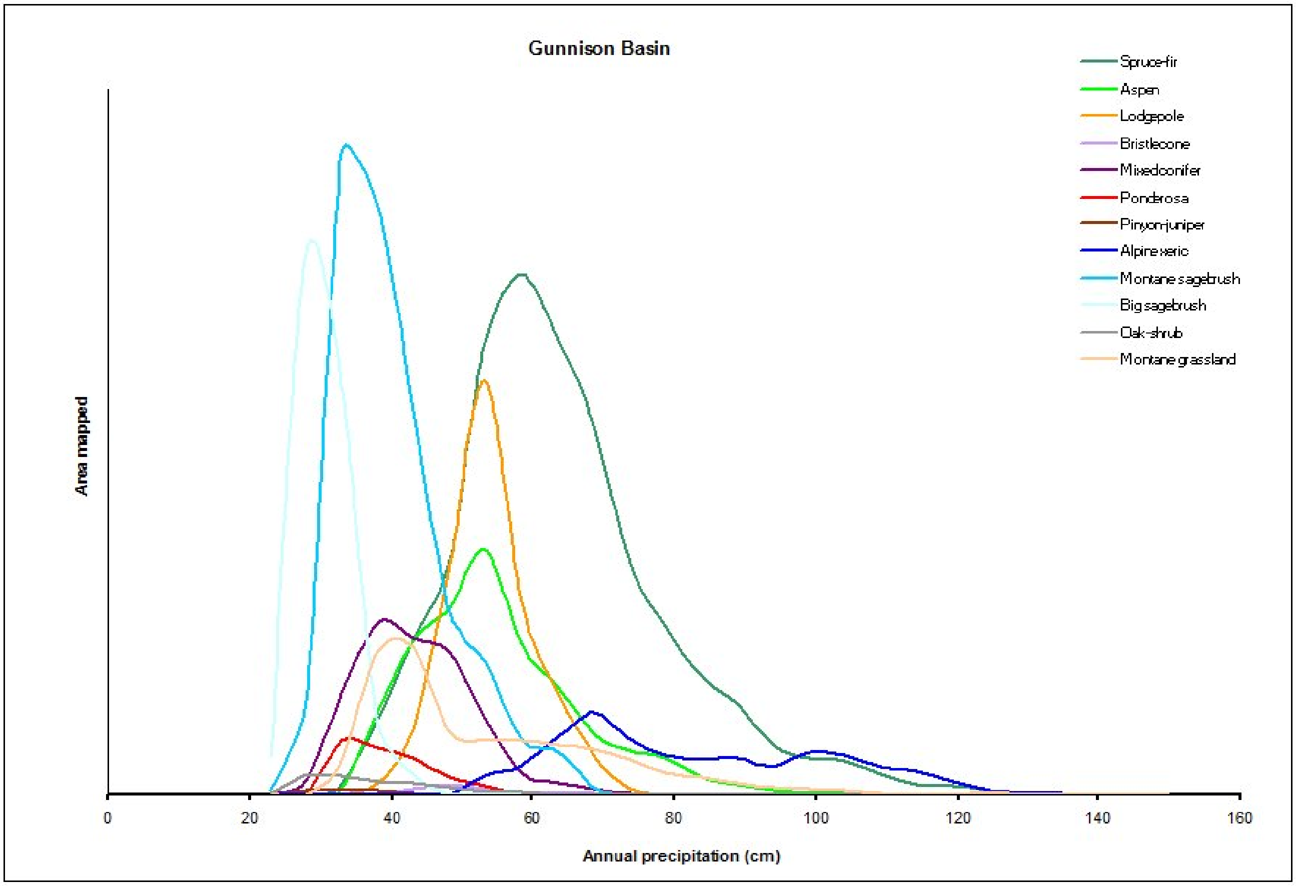

Figure 2. Precipitation

	Annual precipitation (cm)		
Ecosystem	**Min**	**Max**	**Mean**
Alpine	**40**	**122**	**83**
Spruce-fir	**40**	**118**	**65**
Aspen	**40**	**109**	**58**
Montane grassland	**33**	**104**	**58**
Lodgepole	**41**	**89**	**57**
Bristlecone	**46**	**79**	**54**
Mixed Conifer	**33**	**81**	**47**
Montane sagebrush	**31**	**75**	**45**
Ponderosa	**36**	**58**	**44**
Oak Mixed shrub	**33**	**77**	**44**
Pinyon-juniper	**31**	**53**	**42**
Big sage shrub	**30**	**48**	**36**

APPENDIX D: Freshwater Ecosystem Vulnerability Assessment Summaries

Author: John Sanderson, The Nature Conservancy

1. SMALL HIGH-ELEVATION STREAMS

Subalpine stream near Mexican Cut© B. Neely

Small high-elevation streams include coldwater aquatic and riparian habitats at higher elevations: upper montane, alpine and subalpine riparian. These systems are generally found above 8500 ft. (yet can extend into lower elevations), have watersheds < 100 km^2, mean annual flow < about 50 cfs, and correspond roughly with stream order 1 and 2. Aquatic experts in the Gunnison Basin note that we may need to split dry south-end headwater streams from wet north-end headwater streams, because they may be vulnerable in different ways, but no attempt has yet been made to analyze these two geographies independently.

Characteristic species: Willow (*Salix* sp.) is the dominant plant along these streams. Brook trout, cutthroat trout, beaver (*Castor canadensis*), and coldwater invertebrates (e.g. stoneflies, mayflies, caddisflies; Canton and Chadwick 1983). These streams provide habitat to boreal toad (*Bufo boreas boreas*), an at-risk species.

Current condition	**Good**
Vulnerability	**Low to Moderate**
Confidence	**High**

Most small high-elevation streams are in the Gunnison National Forest. Although subject to grazing, fragmentation by roads, and recreation, these stream systems are generally in good condition. For example, Alexander and Brown (2009) found that, overall, the riparian condition of Coal Creek, its tributaries and lakes is in relatively healthy condition. However, pockets of high and even extreme degradation do exist. For example, the eroded slope on the north side of Kebler Pass Road east of the Mt. Emmons Mine access road contributes noticeable sediment to Coal Creek (Alexander and Brown 2009). Several high-elevation streams are impacted by heavy metals, specifically Coal Creek (cadmium and zinc), Henson Creek and Oh-Be-Joyful Creek (cadmium). Because many of these streams are on public land, expansion of roads and other development is unlikely.

Although most models show that higher elevations will experience relatively greater temperature increases, current temperatures are typically cold limiting for many species above 9,000 feet, including pathogens and non-native species. For example, temperatures for trout are well below thermal limits

(Coleman and Fausch 2007), so the 2050 temperature increases are not expected to approach the upper thermal limits for trout. More likely, higher elevation streams could provide refuge from warming at lower elevations (see Wenger et al. 2011). However, small streams have limited capacity to support trout, especially large trout, so declines in base flow resulting from earlier snowmelt could act in the opposite direction, forcing trout downstream. Competition and hybridization from introduced trout can prevent native cutthroat trout from moving downstream (Wenger et al. 2011). Increased temperatures are expected to lead to earlier peak flows, but sensitivity of high elevation ecosystem function to these hydrologic changes is expected to be low, in part because the geomorphology of many of these streams is bedrock constrained. However, Harper and Peckarsky (2006) found that an earlier peak flow lead resulted in earlier emergence of a mayfly species with earlier emerging females producing fewer offspring. If a similar dynamic occurs across many aquatic invertebrates, ecological consequences could be significant.

The probability of fire and resulting ash and sediment flows will increase, but likely not at a large enough scale to affect species occurring over a large number of high-elevation streams. But such catastrophic events could have grave consequence for conservation populations of cutthroat trout that are already isolated to a few small streams (James J. Roberts, Postdoctoral Research Associate, CSU, pers.comm.).

Table 1. Summary table of vulnerability factors evaluated for small high-elevation streams.

Vulnerability Factor	Rating	Comments
Current loss / stressors	Low	On USFS land, mostly in good condition.
Vulnerability to increasing temperatures	Low	These cold habitats are expected to stay below known thermal limits; Increases in stream temperatures at higher elevations may benefit fish populations by making these streams more productive by increasing growth rates (Howe et al. 2011). Invertebrate response to warmer temperatures is unknown.
Vulnerable to pathogens	Low	Invasive species not currently a problem at these higher elevations; future low temperatures expected to keep it that way.
Vulnerability to increased damage from invasive species	Low	Invasive species not currently a problem at these higher elevations; future low temperatures expected to keep it that way.
Restricted to specific hydro-geomorphic setting restricted to specific geomorphic setting	Medium	Mostly at their upper elevation limit and cannot move higher.
Vulnerability to extreme events	Medium	Sedimentation following fires could be locally severe.
Dependence on snowmelt magnitude and timing	Medium	Being high in watershed and mostly bedrock constrained limits keeps dependence modest.
Vulnerable to decreasing baseflows	Medium	Baseflows expected to decrease modestly (Markstrom et al. *in press*).
Likely future impacts of non-climate stressors (including human response to climate change)	Low	High-elevation lands mostly protected.

2. MID-SIZE STREAMS

East River valley below Gothic © R. Rondeau

Mid-size streams include coldwater aquatic habitats and shrubland montane riparian (including riparian wetlands). These streams extend between 7,500 feet and 9,000 feet (2290-2740 m) above sea level (ASL) with Blue Mesa Reservoir demarking the lower boundary. Typically watersheds 100-1000 km^2, corresponding roughly with stream order 3 and 4. Examples include Tomichi Creek, Slate River, and Middle Lake Fork. On USFS lands alone there are over 2300 miles of mid-size streams (Howe et al. 2011).

Characteristic species: include rainbow trout, cutthroat trout, brown trout, narrowleaf cottonwood, blue spruce, *Salix* spp., beaver, great blue heron, sandhill crane, American dipper, Swainson's thrush, and leopard frogs.

Current condition	**Good**
Vulnerability	**Moderate to High**
Confidence	**Medium**

Most mid-size streams in the Upper Gunnison Basin are in good condition. However, some are affected by sedimentation, unstable stream banks, and other factors, with some prominent stresses in highly localized area. The Slate River is impacted by high levels of zinc (Colorado Department of Public Health and Environment 2008).

Elevations that start to experience winter rain under a warmer climate are expected to impact brown trout and brook trout whose eggs remain in the gravel through winter and so can be washed away by winter floods (Wenger et al. 2011). A widespread and large increase in the proportion of precipitation falling as rain rather than snow has been observed elsewhere in the West, but so far these changes are smaller and less significant in Colorado (Ray et al. 2008), but it remains to be seen if winter rain will increase in the Gunnison basin.

Aquatic macro-invertebrates can be highly sensitive to stream temperature, with potential consequences for food webs. For example, earlier snowmelt—projected to result from increased air temperatures and leading to warmer stream temperatures earlier in the year—has been documented to result in earlier emergence of a mayfly species (Harper and Peckarsky 2006). The earlier-emerging females are less fecund than females that emerge later (Peckarsky et al. 2001).

It is possible that some mid-size streams originating at lower elevations (i.e., do not have mountainous headwaters) could see water temperatures exceed the preferences of trout during summer. For example, Gold Basin Creek near the town of Gunnison (101 km^2 watershed) is slightly above optimal temperatures at present (annual air temperature of 53.4° F averaged over the watershed, as a surrogate for water temperature). The projected increases (3.6° to 5.4° F by 2050) could see trout moving to cooler streams during summer to avoid stressful conditions, if they do not already. Similar 'tracking' of temperature changes by moving to higher elevations may be possible for many lentic species where there are not barriers to dispersal (Rieman and Isaak 2010).

Didymo is known to occur in the East River and likely other mid-size streams, and it appears to be spreading in extent and increasing in abundance. Neither the ecological consequences nor the causes of this increase is understood, it may be linked to climate (Ian Billick, RMBL, pers. communication).

Table 2. Summary table of vulnerability factors evaluated for mid-sized streams.

Vulnerability Factor	Rating	Comments
Current loss / stressors	Low	Generally in good condition, but with isolated fair to poor condition.
Vulnerability to increasing temperatures	Medium	May approach thermal limits of some species.
Vulnerable to pathogens	Medium	Some pathogens already present.
Vulnerability to increased damage from invasive species	Low	Temperatures expected to still be too low for most invasive species.
Restricted to specific hydro-geomorphic setting	Low	Both plants and animals should be able to relocate upstream in most instances.
Vulnerability to extreme events	Medium	Sedimentation following fires could be locally severe.
Dependence on snowmelt magnitude and timing	High	Geomorphic changes could be large; biological responses of fish and inverts may be significant.
Vulnerable to decreasing baseflows	High	Lower flow, particularly in late summer, could exacerbate temperature and other effects.
Likely future impacts of non-climate stressors (including human response to climate change)	Medium	In several locations, these streams will be affected by population growth and future water demand.

3. RIVERS

Gunnison River © K. Alexander

Rivers are large lotic habitats that include the Gunnison River, the lower Taylor River, the bottom end of Tomichi Creek, and the lower end of the Lake Fork. These systems have watersheds >1000 km^2, corresponding with stream order 5 up to 7. Rivers frequently have wide, complex river channels and extensive floodplain habitats.

Characteristic species: include brown trout and rainbow trout live year-round in rivers, and kokanee seasonally migrate into rivers to spawn. Other animals include leopard frog, river otter, beaver, bald eagle, great blue heron, and sandhill cranes. Historically, flannel mouth sucker and blue head sucker occurred in these rivers, but at present these populations are so reduced, disconnected from larger populations, and hybridized with non-native suckers that they are not a management consideration. A complex mix of narrowleaf cottonwood (*Populus angustifolia*), willow (*Salix* sp.), meadows, and wetlands occur in the riparian areas.

Current condition	**Good**
Vulnerability	**Moderate to High**
Confidence	**Medium**

Current condition of rivers ranges from fair to good, depending on the component being considered. For riparian areas, BioEnvirons (2010) found that 87% of linear miles of the mainstem of the Gunnison River between Almont and McCabe's Bridge (~3 miles below the town of Gunnison) is in proper functioning condition. However, 50% of riparian forest habitat in this reach has been lost.

Although the non-native salmonids populations are healthy, the natural suite of native fish species in the Upper Basin has been highly compromised. These populations likely can never be restored because Blue Mesa reservoir permanently disconnects the Upper Basin from below the reservoir, and also because the rivers contain non-native white suckers (*Catostomus commersoni*) and longnose suckers (*Catostomus catostomus*), both of which hybridize with native flannelmouth suckers. These hybrids have facilitated introgression with native bluehead suckers (McDonald et al. 2008), which now which now also carry an abundance of non-native sucker genes.

The temperature regime in 2050 may remain within acceptable limits for trout, because much of the water in the large rivers originates at high elevations. For example, the lowest elevation in the study area (Gunnison River at Blue Mesa Dam, ~7,500ft) could increase from near-optimal temperatures at present (annual air temperature of 50° F averaged over the watershed), to higher than optimal temperatures (projected increase of 3.6° to 5.4° F by 2050), but not approach lethal temperatures. However, Haak et al. (2010) indicate a moderate risk of summer temperatures being excessively high.

Table 3. Summary table of vulnerability factors evaluated for rivers.

Vulnerability Factor	Rating	Comments
Current loss / stressors	Low	Generally in good condition, but with isolated fair to poor condition. However, much of original riparian is lost.
Vulnerability to increasing temperatures	Medium	May approach thermal limits of some species.
Vulnerable to pathogens	Medium	Some pathogens already present.
Vulnerability to increased damage from invasive species	Low	Temperatures expected to still be too low for most invasive species.
Restricted to specific hydro-geomorphic setting	Low	Both plants and animals should be able to relocate upstream in most instances.
Vulnerability to extreme events	Medium	Sedimentation following fires could be locally severe.
Dependence on snowmelt magnitude and timing	High	Geomorphic changes could be large; biological responses of riparian plants, fish and invertebrates may be significant.
Vulnerable to decreasing baseflows	High	Lower flow, particularly in summer, could exacerbate temperature and other effects.
Likely future impacts of non-climate stressors (including human response to climate change)	Medium	In several locations, rivers will be affected by population growth and future water demand.

4. HIGH-ELEVATION, GROUNDWATER-DEPENDENT WETLANDS

Mexican Cut wetland © B. Neely

High-elevation, groundwater-dependent wetlands include fens, seeps and springs, and other wetlands above about 9,000 ft. ASL that are not strongly associated with stream systems. Most of these wetlands are supplied by groundwater. Occurrences of these wetlands are often small and discrete locations on the landscape. In some areas, this ecosystem can be quite common, cover up to 19% of a subwatershed (6 digit Hydrologic Unit Code; Howe et al. 2011).

Characteristic species: include willows (*Salix* spp., esp. *S. planifolia*) and sedges (both highly prevalent). These wetlands support boreal toads. Diverse and abundant invertebrates are associated with these wetlands, and dragonflies are common.

Current condition	**Fair**
Vulnerability	**Low to Moderate**
Confidence	**High**

A substantial portion of high elevation wetlands are on public land that offers some level of protection; however, many of these wetlands have been impacted to some degree by livestock grazing and trampling, roads, and off-road vehicles. These impacts may increase with as the human population in the region grows, but impacts could be offset by an increased focus on management for high-condition wetlands.

Changes in hydrology could affect high-elevation wetlands, but there is still high uncertainty about how these changes may change wetland ecosystem function. Although March 1 snowpack is expected to be relatively un-impacted by climate change (J. Barsugli, pers. comm.), snowmelt will occur earlier, resulting in a longer growing season. This growing season will also be warmer than it is currently. With a longer, warmer summer, wetlands that currently have a marginal water supply may dry up. Also, if there is an overall decrease in water supply, we would expect less wetland extent and loss of small wetland areas. Higher temperatures, smaller water supplies, and lower average water table could result in a reduction or reversal of peat accumulation (Chimner and Cooper 2003). However, modeling of groundwater flows suggest relatively little change (Markstrom et al. *in press*), supporting anecdotal observations that droughts may have little impact on fens. A ‘medium’ confidence in vulnerability to decreasing water supply is driven by uncertainty in summer monsoon projections and long-term trends in groundwater supplies.

Table 4. Summary table of vulnerability factors evaluated for high-elevation, ground-water dependent wetlands.

Vulnerability Factor	Rating	Comments
Current loss / stressors	Medium	Impacts from grazing and off-road vehicles.
Vulnerability to increasing temperatures	Medium	Could increase evapotranspiration; may approach thermal limits of some organisms.
Vulnerable to pathogens	Low	Pathogens not known nor anticipated to be a problem.
Vulnerability to increased damage from invasive species	Low	Invasive species not know or anticipated to be a problem.
Restricted to specific hydro-geomorphic setting	High	These wetlands cannot move—they are restricted to specific locations on the landscape.
Vulnerability to extreme events	Low	Local impacts from sedimentation following could be high, but generally expected to be low because of high elevation.
Dependence on snowmelt magnitude and timing	Low	Not dependent on streamflow.
Vulnerable to decreasing baseflows	Medium	May be less groundwater discharge to these wetlands (Markstrom et al. *in press*).
Likely future impacts of non-climate stressors (including human response to climate change)	Low	These wetlands afforded increasingly high levels of protection by USFS.

5. MONTANE GROUNDWATER-DEPENDENT WETLANDS

Groundwater-fed wet meadow near Tomichi Creek © B. Neely

Montane groundwater-dependent wetlands include seeps, springs, and ephemeral wet meadows below approximately 9,000 feet ASL. Seeps and springs are small wetland ecosystems that are hydrologically supported by groundwater discharge (Sada et al. 2001). They are distinctive from other wetland and riparian habitats by the relatively constant water temperature and chemistry of the discharging groundwater (Sada et al. 2001). Occurrences of these wetlands tend to be small and are often isolated in an otherwise large matrix of terrestrial vegetation.

Characteristic species: include aquatic plants, e.g., pondweed (*Potamogeton* sp.) and duckweed (*Lemna* sp.), but more typically are dominated by sedges (*Carex* spp.), rushes (*Juncus balticus* and *J. saximontanus*), and grasses (esp. *Agrostis gigantea* and *Glyceria striata*), with occasional woody vegetation, especially such as thinleaf alder (*Alnus incana*) and various willows (*Salix* spp.). Rocky Mountain iris (*Iris montana*), which is found in higher numbers in areas with moderate to high intensity grazing, is commonly found in these wetlands. Leopard frogs (*Rana pipiens*) are the most frequently encountered amphibian in these wetlands. Low-elevation groundwater dependent wetlands have great importance as brood rearing habitat for Gunnison Sage Grouse (*Centrocercus minimus*).

Current condition	**Poor**
Vulnerability	**High**
Confidence	**High**

Montane groundwater-dependent wetlands are typically highly impacted by development of springs as water supplies, livestock grazing, road placement, real estate development, and non-native invasive plants. Doyle (2003) listed approximately 10% of the seeps and springs in the Gunnison Basin as "highest quality", and fewer than half in "Proper Functioning Condition". Springs and seeps source-water is relatively unaltered because there are no significant groundwater quality degradation or depletions.

Their small size and occurrence at lower elevations with warmer temperatures make groundwater dependent wetlands particularly vulnerable to severe drought. Doyle (2003) noted that many of the seeps and springs in the Gunnison Basin were dry during the 2002 field season due to extended drought conditions.

Table 5. Summary table of vulnerability factors evaluated for montane groundwater-dependent wetlands.

Vulnerability Factor	Rating	Comments
Current loss / stressors	High	Substantial and widespread impacts from water development, grazing, and weeds.
Vulnerability to increasing temperatures	High	Expect higher evapotranspiration at the same time that demand for water is increasing.
Vulnerable to pathogens	Medium	Expect more conducive environment.
Vulnerability to increased damage from invasive species	High	Expect more conducive environment.
Restricted to specific hydro-geomorphic setting	High	Typically restricted to specific locations on the landscape.
Vulnerability to extreme events	Low	Neither fires nor floods expected to have high impact, although drought can reduce number and area of wetlands.
Dependence on snowmelt magnitude and timing	Low	Not snowmelt dependent.
Vulnerable to decreasing baseflows	High	Decreases in groundwater discharge would reduce occurrences.
Likely future impacts of non-climate stressors (including human response to climate change)	High	Demand on these resources can be expected to increase with higher temperatures and drier conditions.

6. HIGH-ELEVATION LAKES

Nicholson Lake © R. Body

High-elevation lakes are natural, open water bodies often formed by a terminal glacial moraine and commonly occurring above 11,000 feet ASL. Some of these lakes have had their outlets modified to control water levels. Examples of high-elevation lakes include Long Lake, Nicholson Lake, Emerald Lake, and Peeler Lake.

Characteristic species: include non-native brook trout (the most common fish species in high-elevation lakes), but there are several that include populations of the native cutthroat trout. Vegetation along the margins of these lakes is pre-dominantly willows and sedges. Spotted sandpipers and American pipits nest along the edges of several of these lakes.

Current condition	**Good**
Vulnerability	**Low to Moderate**
Confidence	**High**

High-elevation lakes occur mostly in National Forest, and many are in designated wilderness. As such, they are largely undeveloped. Water management is generally low and water quality is high. Changes in water supplies to these lakes will affect ecological function, yet there is uncertainty about what these changes might be. However, productivity of these lakes is increasing with deposition of atmospheric nitrogen (Baron et al. 2000), with a more complex role for climate (Williams et al. 1996) and the possibility that the oligotrophic nature of these lakes could change. Smol et al. (2005) documented large changes in algal and invertebrate communities in arctic lakes, which may suggest similar possibilities in the Upper Gunnison.

Table 6. Summary table of vulnerability factors evaluated for high-elevation lakes.

Vulnerability Factor	Rating	Comments
Current loss / stressors	Low	High human use along shorelines, but otherwise in good condition.
Vulnerability to increasing temperatures	Low	Relatively large size should buffer summer temperatures.
Vulnerable to pathogens	Low	Pathogens not known nor anticipated to be a problem.

Vulnerability Factor	Rating	Comments
Vulnerability to increased damage from invasive species	Low	Invasive species not know or anticipated to be a problem.
Restricted to specific hydro-geomorphic setting	High	These lakes cannot move—they are restricted to specific locations on the landscape.
Vulnerability to extreme events	Low	Geomorphic setting does not make these lakes especially vulnerable to extreme events.
Dependence on snowmelt magnitude and timing	Low	Not highly dependent on streamflows.
Vulnerable to decreasing baseflows	Medium	May be less water flowing into these wetlands, but these is unclear.
Likely future impacts of non-climate stressors (including human response to climate change)	Low	These lakes afforded high levels of protection by USFS.

7. RESERVOIRS AND ASSOCIATED WETLANDS

Blue Mesa Reservoir

Reservoirs and associated wetlands are represented by three large reservoirs in the study area: Blue Mesa, Taylor, and San Cristobal. These lentic ecosystems are characterized by deep water and a heavily influenced by management of releases from the water body as well as management of the fish resources. The vegetation along the margins of these reservoirs is influenced by the water management, and most of the species present can survive widely fluctuating water levels.

Characteristic species: include the kokanee, lake trout, brown trout, and yellow perch. Osprey is commonly seen near reservoirs. There are abundant non-native species in reservoirs.

Current condition	**Fair**
Vulnerability	**Moderate to High**
Confidence	**Low**

Reservoirs are highly-managed ecosystems with respect to both water levels (storage) and wildlife resources. Climate-driven hydrologic models indicate greater fluctuation of water levels, possibly making it more difficult to manage for specific resources. Some of the decrease in water supply will be managed by reservoir operations. However, it is very difficult to speak confidently to this aspect of the future of the reservoirs because this is a very complex system driven by water rights administration. Extreme fluctuations in reservoirs level could make it more difficult to manage shorelines, fish populations, and water quality.

Table 7. Summary table of vulnerability factors evaluated for reservoirs and associated wetlands.

Vulnerability Factor	Rating	Comments
Current loss / stressors	Medium	Reservoirs currently in decent condition, but some issues at Blue Mesa.
Vulnerability to increasing temperatures	Medium	Unclear what these effects may be, but difficult to project.
Vulnerable to pathogens	Medium	Major changes in hydrology and temperature could make reservoirs more vulnerable to pathogens.

Vulnerability Factor	Rating	Comments
Vulnerability to increased damage from invasive species	High	Several invasives already present, and these expected to increase with warmer temperatures and greater fluctuations in water levels.
Restricted to specific hydro-geomorphic setting	High	Location is fixed.
Vulnerability to extreme events	Low	Large size buffers extreme events.
Dependence on snowmelt magnitude and timing	Low	Large size buffers short-term effects of snowmelt.
Vulnerable to decreasing baseflows	Medium	Over time, reduced flows lead to lower water levels and greater fluctuations in levels.
Likely future impacts of non-climate stressors (including human response to climate change)	Medium	Expect more demand for water.

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APPENDIX E: Climate Change Vulnerability Index Scoring Category

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Definitions

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Section B – Indirect Exposure to Climate Change

1. **Exposure to sea level rise**: not applicable to Colorado. All species rated 'Neutral.'

2. **Distribution relative to natural barriers**: degree to which species' vulnerability is influenced by its ability to shift range/distribution in response to climate change. The geographical features of the landscape where a species occurs may naturally restrict it from dispersing to inhabit new areas (IPCC 2002, Midgley et al. 2003, Simmons et al. 2004, Koerner 2005, Thuiller et al. 2005, Jiguet et al. 2007, Benito Garzón et al. 2008, Hawkins et al. 2008, Loarie et al. 2008, Lenoir et al. 2008, Price 2008). Similarly, dispersal may be hindered by intervening anthropogenically altered landscapes such as urban or agricultural areas for terrestrial species or dams and culverts for aquatic species (Parmesan 1996).

Scoring categories for both natural barriers and anthropogenic barriers are:

Greatly Increase Vulnerability:	Barriers completely OR almost completely surround the current distribution such that the species' range in the assessment area is unlikely to be able to shift significantly with climate change, or the direction of climate change-caused shift in the species' favorable climate envelope is fairly well understood and barriers prevent a range shift in that direction. See *Neutral* for species in habitats not vulnerable to climate change.
	Examples for natural barriers: lowland terrestrial species completely surrounded by high mountains (or bordered closely and completely on the north side by high mountains); cool-water stream fishes for which barriers would completely prevent access to other cool-water areas if the present occupied habitat became too warm as a result of climate change; most non-volant species that exist only on the south side of a very large lake in an area where habitats are expected to shift northward with foreseeable climate change.
	Examples for anthropogenic barriers: species limited to small habitats within intensively developed urban or agricultural landscapes through which the species cannot pass, A specific example of this category is provided by the quino checkerspot butterfly (*Euphydryas editha quino*), a resident of northern Baja California and southern California; warming climates are forcing this butterfly northward, but urbanization in San Diego blocks its movement (Parmesan 1996, Nature 382:765).
Increase Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be greatly but not completely or almost completely impaired.
	Examples for natural barriers: certain lowland plant or small mammal species whose ranges are mostly (50-90%) bordered by high mountains or a large lake.

	Examples for anthropogenic barriers: most streams inhabited by a fish species have dams that would prevent access to suitable habitat if the present occupied habitat became too warm as a result of climate change; intensive urbanization surrounds 75% of the range of a salamander species.
Somewhat Increase Vulnerability:	Barriers border the current distribution such that climate change-caused distributional shifts in the assessment area are likely to be significantly but not greatly or completely impaired.
	Examples for natural barriers: certain lowland plant or small mammal species whose ranges are partially but not mostly bordered by high mountains or a large lake.
	Examples for anthropogenic barriers: 10-50% of the margin of a plant species' range is bordered by intensive urban development; 25% of the streams occupied by a fish species include dams that are likely to impede range shifts driven by climate change.
Neutral:	Significant barriers do not exist for this species, OR small barriers exist in the assessment area but likely would not significantly impair distributional shifts with climate change, OR substantial barriers exist but are not likely to contribute significantly to a reduction or loss of the species' habitat or area of occupancy with projected climate change in the assessment area.
	Examples of species in this category: most birds (for which barriers do not exist); terrestrial snakes in extensive plains or deserts that may have small barriers that would not impede distributional shifts with climate change; small alpine-subalpine mammal (e.g., ermine, snowshoe hare) in extensive mountainous wilderness area lacking major rivers or lakes; fishes in large deep lakes or large main-stem rivers that are basically invulnerable to projected climate change and lack dams, waterfalls, and significant pollution; a plant whose climate envelope is shifting northward and range is bordered on the west by a barrier but for which no barriers exist to the north.

3. **Impact of land use changes resulting from human responses to climate change**: This factor is intended to identify species that might be further threatened by strategies designed to mitigate or adapt to climate change. Strategies designed to mitigate greenhouse gases, such as creating large wind farms, plowing new cropland for biofuel production, or planting trees as carbon sinks, have the potential to affect large tracts of land and the species that use these areas in both positive and negative ways (Johnson et al. 2003).

Definitions of scoring categories are:

Increase Vulnerability:	The natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that are likely to very likely to occur within its current and/or potential future range. This includes (but is not limited to) the following: ✓ Species requiring open habitats within landscapes likely to be reforested or afforested. If the species requires openings within forests that are created/maintained by natural processes (e.g., fire), and if those processes have a reasonable likelihood of continuing to operate within its range, a lesser impact category may be appropriate.

	✓ Bird and bat species whose migratory routes, foraging territory, or lekking sites include existing and/or suitable wind farm sites. If numerous wind farms already exist along the species' migratory route, negative impacts have been found in relevant studies; if such studies exist but negative impacts have not been found, a lesser impact category may be appropriate. ✓ Greater than 20% of the species' range within the assessment area occurs on marginal agricultural land, such as CRP land or other open areas with suitable soils for agriculture ("prime farmland", etc.) that are not currently in agricultural production OR > 50% of the species' range within the assessment area occurs on any non-urbanized land with suitable soils, where there is a reasonable expectation that such land may be converted to biofuel production. ✓ The species occurs in one or more river/stream reaches not yet developed for hydropower, but with the potential to be so developed. ✓ Species of deserts or other permanently open, flat lands with potential for placement of solar arrays. ✓ Species dependent on dynamic shoreline habitats (e.g., active dunes or salt marshes) likely to be destroyed by human fortifications against rising sea levels.
Somewhat Increase Vulnerability:	The natural history/requirements of the species are known to be incompatible with mitigation-related land use changes that *may possibly* occur within its current and/or potential future range, including any of the above (under Increase).
Neutral:	The species is unlikely to be significantly affected by mitigation-related land use changes that may occur within its current and/or potential future range, including any of the above; OR it is unlikely that any mitigation-related land use changes will occur within the species' current and/or potential future range.
Somewhat Decrease Vulnerability:	The species is likely to benefit from mitigation-related land use changes that may occur within its current and/or potential future range. This includes (but is not limited to) the following: ✓ Forest-associated species currently found within a landscape with < 40% forest cover, where increases in forest cover may occur as a result of reforestation or afforestation projects. ✓ Species currently subject to a higher frequency of fires than experienced historically, where there may now be greater incentive to control such fires. ✓ Species occurring on unprotected lands which may be protected and managed for conservation due to their carbon storage and/or sequestration ability.
Decrease Vulnerability:	The species is likely to benefit from mitigation-related land use changes that are likely to very likely to occur within its current and/or potential future range, including any of the above (under Somewhat Decrease).

Section C - Sensitivity

1. **Dispersal and movement.** Species with poor dispersal abilities may not be able to track fast-moving, favorable climates (Dyer 1995, Midgley et al. 2003, Williams et al. 2005, Jiguet et al. 2007).

Definitions of scoring categories are:

Greatly Increase Vulnerability:	Species is characterized by severely restricted dispersal or movement capability. This category includes species represented by sessile organisms that almost never disperse more than a few meters per dispersal event. Examples include: plants with large or heavy propagules for which the disperser is extinct or so rare as to be ineffective; species with dispersal limited to vegetative shoots, buds, or similar structures that do not survive (at least initially) if detached from the parent.
Increase Vulnerability:	Species is characterized by highly restricted dispersal or movement capability. This category includes species that rarely disperse through unsuitable habitat more than about 10 meters per dispersal event, and species in which dispersal beyond a very limited distance (or outside a small isolated patch of suitable habitat) periodically or irregularly occurs but is dependent on highly fortuitous or rare events. Examples include: plants dispersed ballisticly; plant or animal species with free-living propagules or individuals that may be carried more than 10 meters by a tornado or unusually strong hurricane or large flood but that otherwise rarely disperse more than 10 meters; plants that do not fit criteria for Greatly Increase but lack obvious dispersal adaptations (i.e., propagules lack any known method for moving more than 10 meters away from the source plant).
Somewhat Increase Vulnerability:	Species is characterized by limited but not severely or highly restricted dispersal or movement capability. A significant percentage (at least approximately 5%) of propagules or individuals disperse approximately 10-100 meters per dispersal event (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include; species that exist in small isolated patches of suitable habitat but regularly disperse or move among patches that are up to 100 meters (rarely farther) apart; many ant-dispersed plant species; plants whose propagules are dispersed primarily by small animals (e.g., some rodents) that typically move propagules approximately 10-100 meters from the source (propagules may be cached or transported incidentally on fur or feathers); plants dispersed by wind with low efficiency (e.g., species with inefficiently plumed seeds and/or that occur predominantly in forests).
Neutral:	Species is characterized by moderate dispersal or movement capability. A significant percentage (at least approximately 5%) of propagules or individuals disperse approximately 100-1,000 meters per dispersal event (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include: species whose individuals exist in small isolated patches of suitable habitat but regularly disperse or move among patches that are 100-1,000 meters (rarely farther) apart; many plant species dispersed by wind with high efficiency (e.g., species with efficiently plumed seeds or very small propagules that occur predominantly in open areas); plant and animal species whose propagules or individuals are dispersed by small animals (e.g., rodents, grouse) that regularly but perhaps infrequently move propagules approximately 100-1,000 meters from the source).

Somewhat Decrease Vulnerability:	Species is characterized by good dispersal or movement capability. Species has propagules or dispersing individuals that readily move 1-10 kilometers from natal or source areas (rarely farther), or dispersal capability likely is consistent with one of the following examples. Examples include: plant species regularly dispersed up to 10 km (rarely farther) by large or mobile animals (e.g., plant has seeds that are cached, regurgitated, or defecated 1-10 kilometers from the source by birds [e.g., corvids, songbirds that eat small fleshy fruits] or mammals or that are transported on fur of large mobile animals such as most Carnivora or ungulates).
Decrease Vulnerability:	Species is characterized by excellent dispersal or movement capability. Species has propagules or dispersing individuals that readily move more than 10 kilometers from natal or source areas, or dispersal capability likely is consistent with one of the following examples.
	Examples include: plant or animal species whose individuals often or regularly are dispersed more than 10 kilometers by migratory or otherwise highly mobile animals, air or ocean currents, or humans, including species that readily become established outside their native ranges as a result of intentional or unintentional translocations by humans.

2. **Sensitivity to temperature and moisture changes**: This factor pertains to the breadth of temperature and precipitation conditions, at both broad and local scales, within which a species is known to be capable of reproducing, growing, or otherwise existing. Species requiring specific moisture and temperature regimes may be less likely to find similar areas as climates change and previously-associated temperature and precipitation patterns uncouple (Saetersdal and Birks 1997, Thomas 2005, Thuiller et al. 2005, Gran Canaria Declaration 2006, Hawkins et al. 2008, Laidre et al. 2008).

(a.i.) **historical thermal niche**: This factor measures large-scale temperature variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean seasonal temperature variation (difference between highest mean monthly maximum temperature and lowest mean monthly minimum temperature). It is a proxy for species' temperature tolerance at a broad scale.

Definitions of scoring categories are:

Greatly Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **very small (< 37° F/20.8° C)** temperature variation in the past 50 years. Includes cave obligates and species occurring in thermally stable groundwater habitats.
Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **small (37 - 47° F/20.8 - 26.3° C)** temperature variation in the past 50 years.
Somewhat Increase Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **slightly lower than average (47.1 - 57° F/26.3 - 31.8° C)** temperature variation in the past 50 years.

Neutral:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **average (57.1 - 77° F/31.8 - 44.0° C)** temperature variation in the past 50 years.
Somewhat Decrease Vulnerability:	Considering the mean seasonal temperature variation for occupied cells, the species has experienced **greater than average (> 77° F/43.0° C)** temperature variation in the past 50 years.

(a.ii.) **physiological thermal niche**: This factor assesses the degree to which a species is restricted to relatively cool or cold environments that are thought to be vulnerable to loss or significant reduction as a result of climate change.

Definitions of scoring categories are:

Greatly Increase Vulnerability:	Species is completely or almost completely (> 90% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Increase Vulnerability:	Species is moderately (50-90% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Somewhat Increase Vulnerability:	Species is somewhat (10-50% of occurrences or range) restricted to relatively cool or cold environments that may be lost or reduced in the assessment area as a result of climate change.
Neutral:	Species distribution is not significantly affected by thermal characteristics of the environment in the assessment area, or species occupies habitats that are thought to be not vulnerable to projected climate change.
Somewhat Decrease Vulnerability:	Species shows a preference for environments toward the warmer end of the spectrum.

(b.i.) **historical hydrological niche**: This factor measures large-scale precipitation variation that a species has experienced in recent historical times (i.e., the past 50 years), as approximated by mean annual precipitation variation across occupied cells within the assessment area.

Definitions of scoring categories are:

Greatly Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **very small (< 4 inches/100 mm)** precipitation variation in the past 50 years.
Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **small (4 - 10 inches/100 - 254 mm)** precipitation variation in the past 50 years.
Somewhat Increase Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **slightly lower than average (11 - 20 inches/255 - 508 mm)** precipitation variation in the past 50 years.
Neutral:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **average (21 - 40 inches/509 - 1,016 mm)** precipitation variation in the past 50 years.

Somewhat Decrease Vulnerability:	Considering the range of mean annual precipitation across occupied cells, the species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years.

(b.ii.) **physiological hydrological niche**: This factor pertains to a species' dependence on a narrowly defined precipitation/hydrologic regime, including strongly seasonal precipitation patterns and/or specific aquatic/wetland habitats (e.g., certain springs, vernal pools, seeps, seasonal standing or flowing water) or localized moisture conditions that may be highly vulnerable to loss or reduction with climate change.

Definitions of scoring categories are:

Greatly Increase Vulnerability:	Completely or almost completely (>90% of occurrences or range) dependent on a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met (e.g., species dependent on springs tied to a regional aquifer that would not be expected to change significantly with climate change), the species should be scored as Neutral. Examples for Greatly Increase include plants that are exclusively or very strongly associated with localized moist microsites (e.g., "hanging gardens" in arid landscapes).
Increase Vulnerability:	Moderately (50-90% of occurrences or range) dependent on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met, the species should be scored as Neutral. Examples for Increase include certain plants whose life cycles are highly synchronized with Mediterranean precipitation patterns in areas vulnerable to large changes in the amount and seasonal distribution of precipitation. Also included are desert or semi-desert plants that frequently occur in but are not restricted to or almost restricted to moisture-accumulating microsites, as well as plants (and animals that depend on these species) for which >50% of populations occur in areas such as sandy soils that are sensitive to changes in precipitation.
Somewhat Increase Vulnerability:	Somewhat (10-50%) dependent on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change AND the expected direction of moisture change (drier or wetter) is likely to reduce the species' distribution, abundance, or habitat quality. If this second condition is not met, the species should be scored as Neutral. Examples: plants (and animals that depend on these species) for which 10-50% of populations occur in areas such as sandy soils that are sensitive to changes in precipitation; certain plants with ranges restricted to seasonal precipitation environments (e.g., summer rainfall deserts) and which have a moderate degree of adaptation to that seasonality.
Neutral:	Species has little or no dependence on a strongly seasonal hydrologic regime and/or a specific aquatic/wetland habitat or localized moisture regime that is highly vulnerable to loss or reduction with climate change OR hydrological requirements are not likely to be significantly disrupted in major portion of the range.

Somewhat Decrease Vulnerability:	Species has very broad moisture regime tolerances OR would benefit by the predicted change in hydrologic regime. Examples include water-limited species that could increase with increasing precipitation or arid-adapted species that could increase in areas with decreasing moisture availability.

(c.) **dependence on specific disturbance regime**: This factor pertains to a species' response to specific disturbance regimes such as fires, floods, severe winds, pathogen outbreaks, or similar events. Species dependent on habitats such as prairies, longleaf pine forests, and riparian corridors that are maintained by regular disturbances (e.g., fires or flooding) are vulnerable to changes in the frequency and intensity of these disturbances caused by climate change (IPCC 2007, Archer and Predick 2008).

Definitions of scoring categories are:

Increase Vulnerability:	Strongly affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that reduces the species' distribution, abundance, or habitat quality. For example, many sagebrush-associated species in regions predicted to experience increased fire frequency/intensity would be scored here due to the anticipated deleterious effects of increased fire on their habitat.
Somewhat Increase Vulnerability:	Moderately affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that reduces the species' distribution, abundance, or habitat quality, OR strongly affected by specific disturbance regime, and climate change is likely to change that regime in a way that causes minor disruption to the species' distribution, abundance, or habitat quality. For example, plants in a river scour community that are strongly tied to natural erosion and deposition flood cycles, which may shift position within the channel rather than disappear as a result of climate change.
Neutral:	Little or no response to a specific disturbance regime or climate change is unlikely to change the frequency, severity, or extent of that disturbance regime in a way that affects the range or abundance of the species.
Somewhat Decrease Vulnerability:	Moderately affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that increases the species' distribution, abundance, or habitat quality. Many fire-adapted plants can be scored here if a predicted increase in fire frequency/intensity is anticipated to be beneficial.
Decrease Vulnerability:	Strongly affected by specific disturbance regime, and climate change is likely to change the frequency, severity, or extent of that disturbance regime in a way that increases the species' distribution, abundance, or habitat quality (e.g., in areas predicted to experience increased fire frequency, invasive grasses that have a strong positive response to fire (e.g., ecosystem function-altering) could be scored here.

(d.) **dependence on ice, ice-edge, or snow covered habitats**: The extent of oceanic ice sheets and mountain snow fields are decreasing as temperatures increase, imperiling species dependent on these habitats (Stirling and Parkinson 2006, IPCC 2007, Laidre et al. 2008).

Definitions of scoring factors are:

Greatly Increase Vulnerability:	Highly dependent (>80% of subpopulations or range) on ice- or snow-associated habitats; or found almost exclusively on or near ice or snow during at least one stage of the life cycle.
Increase Vulnerability:	Moderately dependent (50-80% of subpopulations or range) on ice- or snow-associated habitats; or often found most abundantly on or near ice or snow but also regularly occurs away from such areas.
Somewhat Increase Vulnerability:	Somewhat (10-49% of subpopulations or range) dependent on ice- or snow-associated habitats, or may respond positively to snow or ice but is not dependent on it. For example, certain alpine plants are often associated with long-lasting snow beds but also commonly occur away from such areas; certain small mammals experience increased survival and may develop relatively large populations under winter snow cover but do not depend on snow cover. Species that benefit from a minimum thickness of ice or snowpack for winter insulation should also be scored here.
Neutral:	Little dependence on ice- or snow-associated habitats (may be highly dependent in up to 10% of the range).

3. **Restriction to uncommon geological features or derivatives -** This factor pertains to a species' need for a particular soil/substrate, geology, water chemistry, or specific physical feature (e.g., caves, cliffs, active sand dunes) for reproduction, feeding, growth, or otherwise existing for one or more portions of the life cycle (e.g., normal growth, shelter, reproduction, seedling establishment). Species requiring specific substrates, soils, or physical features such as caves, cliffs, or sand dunes may become vulnerable to climate change if their favored climate conditions shift to areas without these physical elements (Hawkins et al. 2008). It focuses on the commonness of suitable conditions for the species on the landscape, as indicated by the commonness of the features themselves combined with the degree of the species' restriction to them. Climate envelopes may shift away from the locations of fixed (within at least a 50 year timeframe) geological features or their derivatives, making species tied to these uncommon features potentially more vulnerable to habitat loss from climate change than are species that thrive under diverse conditions.

Definitions of scoring categories are:

Increase Vulnerability:	**Very highly dependent** upon, i.e., more or less endemic to (> 85% of occurrences found on) a particular highly uncommon geological feature or derivative (e.g., soil, water chemistry). Such features often have their own endemics. Examples include serpentine (broad and strict) endemic plants, plants of calcareous substrates where such substrates are uncommon (e.g., California, southeastern U.S.), plants restricted to one or a few specific rock strata, organisms more or less restricted to inland sand dunes or shale barrens, obligate cave-dwelling organisms, and springsnails restricted to springs with high dissolved CO_2. This category could also include fish species that require a highly uncommon substrate particle size for their stream bottoms, such as the Colorado pikeminnow (*Ptychocheilus lucius*) that spawns only on rare cobble bars cleared of debris by strong upstream currents.

Somewhat Increase Vulnerability:	**Moderately to highly dependent** upon a particular geological feature or derivative, i.e., (1) an indicator of but not an endemic to (65-85% of occurrences found on) the types of features described under Increase, OR (2) more or less restricted to a geological feature or derivative that is not highly uncommon within the species' range, but is not one of the dominant types. Examples of the latter include species more or less restricted to active coastal sand dunes, cliffs, salt flats (including shorebirds that require sodic soils), inland waters within a particular salinity range, and non-dominant rock types such as occasional igneous rock intrusions within a landscape mostly dominated by sedimentary and/or metamorphic rocks. This category could also include fish species that require a specific substrate particle size for their stream bottoms, if that type of stream bottom is not one of the dominant types within the species' range.
Neutral:	Having a **clear preference** for (> 85% of occurrences found on) a certain geological feature or derivative, where the feature is among the dominant types within the species' range. For example, red spruce prefers acidic, organic soils (not uncommon within its range), although it is occasionally found on other soil types. Many species whose habitat descriptions specify one pH category (acidic, neutral, or basic) and/or one soil particle size (e.g., rocky, sandy, or loamy) will probably fall here, upon confirmation that the substrate type is not particularly uncommon within the species' range.
Somewhat Decrease Vulnerability:	**Somewhat flexible but not highly generalized** in dependence upon geological features or derivatives, i.e., found on a subset of the dominant substrate/water chemistry types within its range. Most habitat descriptions that mention more than one type of relatively widespread geological feature should probably go here; however, if all types mentioned are uncommon within the species' range, Somewhat Increase may be appropriate. This category also encompasses species not strongly tied to any specific geological feature or derivative, such as many birds and mammals.
Decrease Vulnerability:	**Highly generalized** relative to dependence upon geological features or derivatives, i.e., the species is described as a generalist and/or a significant proportion of its occurrences have been documented on substrates or in waters that represent opposite ends of the spectrum of types within the assessment region (e.g., many occurrences known from both acidic and basic soils or waters, or from both sandy and clay soils). Species such as common yarrow (*Achillea millefolium*) and coyote (*Canis latrans*) should be assigned to this category.

4. **Reliance on specific interactions -** The primary impact of climate change on many species may occur via effects on synchrony with other species on which they depend, rather than through direct physiological stress. Because species will react idiosyncratically to climate change, those with tight relationships with other species may be threatened (Bruno et al. 2003, Hampe 2004, Simmons et al. 2004, Hawkins et al. 2008, Laidre et al. 2008).

(a) **Dependence on other species to generate habitat**:

Definitions of scoring categories are:

Greatly Increase Vulnerability:	Required habitat generated primarily by one species, and that species is highly to extremely vulnerable to climate change within the assessment area.
Increase Vulnerability:	Required habitat generated primarily by one species, and that species is at most moderately vulnerable to climate change within the assessment area. See examples of species requiring other species to generate habitat under Greatly Increase Vulnerability. If the climate change vulnerability of the habitat-generating species is unknown, check both Greatly Increase and Increase Vulnerability.
Somewhat Increase Vulnerability:	Required habitat generated primarily by one or more of not more than a few species. For example, a certain degree of specificity exists between particular cactus species and certain nurse plants; burrowing owls (*Athene cunicularia*) depend on excavations made by relatively few species of burrowing mammals; certain plant species depend on large grazing animals to generate disturbance required for establishment and early growth.
Neutral:	Required habitat generated by more than a few species, or does not involve species-specific processes.

(b) **Dietary versatility**: animals only. This factor pertains to the diversity of food types consumed by animal species. Dietary specialists are more likely to be negatively affected by climate change than are species that readily switch among different food types.

Definitions of scoring categories are:

Increase Vulnerability:	Completely or almost completely (>90%) dependent on one species during any part of the year. For example, Clark's nutcracker (*Nucifraga columbiana*) depends heavily on the seeds of whitebark pine (*Pinus albicaulis*).
Somewhat Increase Vulnerability:	Completely or almost completely (>90%) dependent during any part of the year on a few species from a single guild that may respond similarly to climate change. For example, the larvae of various fritillary butterflies rely heavily on a few species of violets; the great purple hairstreak is dependent on a few mistletoe species.
Neutral:	Diet flexible; not dependent on one or a few species. For example, the diet of the great horned owl (*Bubo virginianus*) is flexible and not strongly dependent on one or a few species (although its diet may be dominated by one or a few species in a particular location).
Somewhat Decrease Vulnerability:	Omnivorous diet including numerous species of both plants and animals.

(c) **Pollinator versatility**: plants only

Definitions of scoring categories are:

Increase Vulnerability:	Completely or almost completely dependent on one species for pollination (> 90% of effective pollination accomplished by 1 species) or, if no observations exist, morphology suggests very significant limitation of potential pollinators (e.g., very long corolla tube).
Somewhat Increase Vulnerability:	Completely or almost completely dependent on 2-4 species for pollination (> 90% of effective pollination accomplished by 2-4 species) or, if no observations exist, morphology suggests conformation to a specific "pollination syndrome" (e.g., van der Pijl 1961, Evolution 15: 44-59, http://www.fs.fed.us/wildflowers/pollinators/syndromes.shtml).
Neutral:	Pollination apparently flexible; five or more species make significant contributions to pollination or, if no observations exist, morphology does not suggest pollinator limitation or pollination syndrome.

(d) **Dependence on other species for propagule dispersal**:

Definitions for scoring categories are:

Increase Vulnerability:	Completely or almost completely (roughly > 90%) dependent on a single species for propagule dispersal. For example, whitebark pine would fit here because Clark's nutcracker is the primary dispersal agent.
Somewhat Increase Vulnerability:	Completely or almost completely (roughly > 90%) dependent on a small number of species for propagule dispersal. For example, a freshwater mussel for which only a few species of fish can disperse larvae.
Neutral:	Disperses on its own (most animals) OR propagules can be dispersed by more than a few species.

(e) **Other inter-specific interactions**: This factor refers to interactions unrelated to habitat, seedling establishment, diet, pollination, or propagule dispersal. Here an inter-specific interaction can include mutualism, parasitism, commensalism, or predator-prey relationship.

Definitions for scoring categories are:

Increase Vulnerability:	Requires an interaction with a single other species for persistence.
Somewhat Increase Vulnerability:	Requires an interaction with a one member of a small group of taxonomically related species for persistence. Could also include cases where specificity is not known for certain, but is suspected. Many Orchidaceae will be in this category because of their requirement for a specific fungal partner for germination (Tupac Otero and Flanagan 2006, TREE 21: 64-65).
Neutral:	Does not require an interspecific interaction or, if it does, many potential candidates for partners are available.

5. **Genetic factors:** A species' ability to evolve adaptations to environmental conditions brought about by climate change is largely dependent on its existing genetic variation (Huntley 2005, Aitken et al. 2008).

(a) **Measured genetic variation**: Species with less standing genetic variation will be less able to adapt because the appearance of beneficial mutations is not expected to keep pace with the rate of 21st century climate change. Throughout this question, "genetic variation" may refer neutral marker variation, quantitative genetic variation, or both. To answer the question, genetic variation should have been assessed over a substantial proportion of a species' range.

Definitions for scoring categories are:

Increase Vulnerability:	Genetic variation reported as "very low" compared to findings using similar techniques on related taxa, i.e., lack of genetic variation has been identified as a conservation issue for the species.
Somewhat Increase Vulnerability:	Genetic variation reported as "low" compared to findings using similar techniques on related taxa.
Neutral:	Genetic variation reported as "average" compared to findings using similar techniques on related taxa.
Somewhat Decrease Vulnerability:	Genetic variation reported as "high" compared to findings using similar techniques on related taxa.

(b) **Occurrence of bottlenecks in recent evolutionary history (use only if C5a is unknown.** In the absence of rangewide genetic variation information (C5a), this factor can be used to infer whether reductions in species-level genetic variation that would potentially impede its adaptation to climate change may have occurred. Only species that suffered population reductions and then subsequently rebounded qualify for the Somewhat Increase or Increase Vulnerability categories.

Definitions of scoring categories are:

Increase Vulnerability:	Evidence that total population was reduced to ≤ 250 mature individuals, to one occurrence, and/or that occupied area was reduced by >70% at some point in the past 500 years.
Somewhat Increase Vulnerability:	Evidence that total population was reduced to 251-1000 mature individuals, to less than 10 occurrences, and/or that occupied area was reduced by 30-70% at some point in the past 500 years.
Neutral:	No evidence that total population was reduced to ≤ 1000 mature individuals and/or that occupied area was reduced by > 30% at some point in the past 500 years.

6. **Phenological response to changing seasonal temperature or precipitation dynamics:** Recent research suggests that some phylogenetic groups are declining due to lack of response to changing annual temperature dynamics (e.g., earlier onset of spring, longer growing season), including European bird species that have not advanced their migration times (Moller et al. 2008), and some temperate zone plants that are not moving their flowering times (Willis et al. 2008) to correspond to earlier spring onset. This may be assessed using either published multi-species studies such as those cited above or large databases such as that of the U.S. National Phenology Network.

Definitions of scoring categories are:

Increase Vulnerability:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, but phenological variables measured for the species show no detectable change
Somewhat Increase Vulnerability:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show some detectable change, but the change is significantly less than that of other species in similar habitats or taxonomic groups.
Neutral:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show detectable change which is average compared to other species in similar habitats or taxonomic groups, OR seasonal dynamics within the species' range show no detectable change.
Somewhat Decrease Vulnerability:	Seasonal temperature or precipitation dynamics within the species' range show detectable change, and phenological variables measured for the species show detectable change which is significantly greater than that of other species in similar habitats or taxonomic groups.

Section D – Documented or modeled response to climate change (to be completed only if relevant species-specific research exists)

1) ***Documented response to recent climate change***. Although conclusively linking species declines to climate change is difficult (Parmesan 2006), convincing evidence relating declines to recent climate patterns has begun to accumulate in a variety of species groups (Parmesan 1996, Parmesan and Yohe 2003, Root et al. 2003, Enquist and Gori 2008). This criterion incorporates the results of these studies when available into the calculation of the Index.

2) ***Modeled future change in range or population size***. The change in area of the predicted future range relative to the current range is a useful indicator of vulnerability to climate change (Midgley et al. 2003, Thomas et al. 2004).

3) ***Overlap of modeled future range with current range***. A spatially disjunct predicted future range indicates that the species will need to disperse in order to occupy the newly favored area, and geographical barriers or slow dispersal rates could prevent the species from getting there (Peterson et al. 2002; Schwartz et al. 2006).

4**) *Occurrence of protected areas in modeled future distribution***. For many species, future ranges may fall entirely outside of protected areas and therefore compromise their long-term viability (Williams et al. 2005).

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APPENDIX F. Species Climate Change Vulnerability Index Results GI = Greatly Increase; Inc = Increase; SI = Somewhat Increase; N = Neutral; SD = Somewhat Decrease; Dec = Decrease; U = Unknown; EV = Extremely Vulnerable; HV = Highly Vulnerable; MV = Moderately Vulnerable; PS = Presumed Stable; IE = Insufficient Evidence to score. (Only the species assessed using the CCVI are included below; see Species section above for list of plant species not assessed using CCVI).

		Temperature Scope		Hamon AET:PET Moisture Metric Scope				Natural barriers	Anthropogenic barriers	Climate change mitigation	Dispersal/Movement	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydrological niche	Dependence on disturbance	Dependence on Ice/snow	Restriction to geological features	Dependence on other species	Diet	Pollinator versatility	Dependence on other species for dispersal	Other species interaction	Genetic variation	Genetic bottlenecks	Phenological response	Documented response	Modeled future change	Overlap of modeled future range	Protected Areas	INDEX SCORE
Species	**English Name**	**A >5.5F**	**A 5.1F**	**< -0.119**	**- 0.119**	**- 0.096**	**- 0.073**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C5a**	**C5b**	**C6**	**D1**	**D2**	**D3**	**D4**	
PLANTS																															
Aliciella sedifolia	Stonecrop gilia	100				93	7	Inc	N	N	N	N	GI	SD	SD	N	GI	SI	N	-	U	N	U	U	U	U	U	U	U	U	**EV**
Astragalus anisus	Gunnison milkvetch	100		45	55			N	N	SI	N	SD	N	Inc	N	N	N	N	N	-	N	U	Inc	U	U	U	U	U	U	U	**PS**
Astragalus microcymbus	Skiff milkvetch	100		97	3			N	SI	SI	N	SD	SI	Inc	Inc	N	N	SI	N	-	N	N	Inc	U	U	U	U	U	U	U	**EV**
Astragalus molybdenus	Leadville Milkvetch	100		22	33	45		Inc	N	N	SI	N	GI	SD	SD	N	Inc	Inc	N	-	N	U	Inc	U	U	U	U	U	U	U	**EV**
Boechera crandallii	Crandall's rock cress	100		36	63	1		N	Inc	SI	N	SD	SI	Inc	N	N	N	N	N	-	N	N	N	U	U	U	U	U	U	U	**HV**
Botrychium echo	reflected moonwort	100		40	40	20		N	N	U	Inc	N	SI	SD	SD	SI	N	N	U	-	N	U	SI	N	-	U	U	U	U	U	**MV**
Botrychium minganense	Mingan's moonwort	100			100			N	N	U	Inc	N	SI	SD	SD	SI	N	N	N	-	N	N	SI	N	-	U	U	U	U	U	**MV**
Botrychium pallidum	pale moonwort	100			100			N	N	U	Inc	N	SI	SD	SD	SI	N	N	U	-	N	U	SI	N	-	U	U	U	U	U	**MV**
Botrychium pinnatum	northern moonwort	100			100			N	N	N	Inc	N	SI	SD	SD	SI	N	N	N	-	N	U	SI	N	-	U	U	U	U	U	**MV**
Braya glabella subsp. Glabella	arctic braya	100		66	34			Inc	N	N	Inc	N	GI	GI	SD	SD	SI	Inc	N	-	U	U	U	Inc	-	U	U	U	U	U	**EV**
Carex stenoptila	Small-winged sedge	79	21		100			N	N	N	Inc	N	N	SI	GI	N	N	SD	N	-	U	N	U	U	U	U	U	U	U	U	**HV**
Cirsium perplexans	Adobe thistle	100			62	38		N	N	SI	SD	N	N	N	N	N	N	SI	N	-	N	N	U	U	U	U	SD	U	U	U	**PS**
Cryptantha weberi	Weber's catseye	100		100				N	N	N	N	N	SI-N	SD	N	N	N	Inc	N	-	N	U	U	U	U	U	U	U	U	U	**PS**
Draba fladnizensis	arctic draba	100		50	50			Inc-SI	N	N	SI	N	GI	SD	SD	SD	Inc	N	N	-	N	U	U	U	U	U	U	U	U	U	**HV**
Draba globosa	rockcress draba	100		100				Inc	N	N	Inc	N	GI	SD	SD	N	Inc	N	N	-	N	U	U	SI	-	U	U	U	U	U	**EV**
Draba rectifructa	mountain whitlow-grass	100			100			N	N	N	SI	SD	N	SD	SD	N	N	N	N	-	N	U	U	U	U	U	U	U	U	U	**IL**
Draba streptobrachia	Colorado Divide whitlow-grass	100				100		Inc	N	N	SI	N	GI	SD	SD	N	Inc	N	N	-	N	U	U	U	U	U	U	U	U	U	**EV**
Drosera rotundifolia	roundleaf sundew	100		100				SI	N	N	SI	N	Inc	SD	GI	N	Inc	Inc	U	-	N	U	U	SI	-	U	U	U	U	U	**EV**
Erigeron humilus	low fleabane	100		50	50			Inc	N	N	N	N	GI	SD	SD	N	Inc	N	N	-	N	N	U	U	U	U	U	U	U	U	**EV**
Erigeron lanatus	woolly fleabane	100		100				Inc	N	U	N	N	GI	SD	SD	N	Inc	SI	N	-	N	N	U	U	U	U	U	U	U	U	**EV**
Eriogonum coloradense	Colorado wild buckwheat	100		10	81	9		Inc	N	N	N	N	Inc	SD	SD	N	Inc	N	N	-	N	N	N	U	U	U	U	U	U	U	**HV**
Eriophorum altaicum var. *neogaeum*	Altai cottongrass	100				100		SI	N	N	SI	N	GI	SD	GI	N	Inc	Inc	N	-	N	N	U	U	U	U	U	U	U	U	**EV**
Gilia penstemenoides	Black Canyon gilia	100		80	20			SI	N	U	N	N	N	Inc	N	N	N	N	N	-	N	U	U	U	U	U	U	U	U	U	**MV**
Luzula subcapitata	Colorado wood-rush	100		100				SI	N	N	SI	N	Inc	SD	GI	N	Inc	N	U	-	N	U	N	U	U	U	U	U	U	U	**EV**
Machaeranthera coloradoensis	Colorado tansy-aster	100			100			SI-N	N	N	N	N	SI-N	SD	SD	N	N	N	N	-	N	N	U	U	U	U	U	U	U	U	**PS**
Penstemon mensarum	Grand Mesa penstemon	100			50		50	N	N	N	N	N	N	U	SD	N	N	N	N	-	N	N	N	U	U	U	U	U	U	U	**PS**
Physaria alpina	Avery Peak twinpod	100			2	98		Inc	N	N	N	N	GI	SD	SD	N	Inc	N	N	-	U	N	U	U	U	U	U	U	U	U	**EV**
Physaria rollinsii	Rollins twinpod	100		22	34	37	7	N	N	N	N	SD	SI	Inc	N	N	N	N	N	-	U	N	U	U	U	U	U	U	U	U	**PS**
Ranunculus gelidus var.	tundra buttercup	100			66.5	33.5		Inc	N	N	N	N	GI	SD	SD	N	GI	N	N	-	N	N	U	U	U	U	U	U	U	U	**EV**

NatureServe		Temperature Scope		Hamon AET:PET Moisture Metric Scope				Natural barriers	Anthropogenic barriers	Climate change mitigation	Dispersal/Movement	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydrological niche	Dependence on disturbance	Dependence on Ice/snow	Restriction to geological features	Dependence on other species	Diet	Pollinator versatility	Dependence on other species for dispersal	Other species interaction	Genetic variation	Genetic bottlenecks	Phenological response	Documented response	Modeled future change	Overlap of modeled future range	Protected Areas	INDEX SCORE
Species	**English Name**	**A >5.5F**	**A 5.1F**	**< -0.119**	**-0.119**	**-0.096**	**-0.073**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C5a**	**C5b**	**C6**	**D1**	**D2**	**D3**	**D4**	
grayi																															
Sullivantia hapemanii var. *purpusii*	Hanging Garden sullivantia	100			30	30	40	Inc	N	U	Inc	N	Inc-SI	SD	GI	N	N	Inc	U	-	N	N	U	U	U	U	U	U	U	U	**EV**
Townsendia rothrockii	Rothrock townsend-daisy	100		16	42	31	11	Inc	N	N	SI	N	Inc	SD	SD	N	Inc	N	N	-	N	N	U	U	U	U	U	U	U	U	**EV**
AMPHIBIANS																															
Anaxyrus boreas boreas	Boreal Toad	100		97	1	2		N	N	N	N-SD	N	SI	SI	GI	SI	SI	N	Inc	N	-	N	N	N	-	U	U	U	U	N	**HV**
Lithobates pipiens	Northern Leopard Frog	100		25	50	25		N	N	N	SD	N	N	Inc-SI	SI	SI	N	SD	SI	N	-	N	N	SI	-	N	Inc-SI	U	U	N	**MV**
BIRDS																															
Accipiter gentilis	Northern Goshawk	100		81	19			N	N	N	Dec	N	N	Inc-SI	N-SD	Inc	N	SD	N	SI-N	-	N	SI-N	SI	-	N	N	SI-N	SI-N	N	**PS**
Aegolius funereus	Boreal Owl	100			25	75		N	N	N	Dec	SI	GI	N	Inc	Inc	SI	N	N	N	-	N	N	SD	-	N	N	N	U	N	**HV**
Amphispiza belli	Sage Sparrow	100		16	84			N	N	N	Dec	SD	N	Inc	N	U	N	SD	U	SD	-	N	N	U	N	U	U	U	U	U	**IL**
Centrocercus minimus	Gunnison Sage-grouse	100		40	60			SI-N	N	N	Dec	SD	N	Inc	GI	Inc	SI	N	N	Inc	-	N	SI-N	Inc-SI	-	U	N	N	U	N	**HV**
Cypseloides niger	Black Swift	100			50	50		N	N	N	Dec	N	N	N	Inc	N	N	SI	N	N	-	N	N	U	N	U	U	U	U	U	**PS**
Falco peregrinus	Peregrine Falcon	100			50	50		N	N	N	Dec	SI	N	N	N	SI-N	N	N	N	N	-	N	N	SI	-	N	N	N	U	N	**PS**
Halieatus leucocephalus	Bald Eagle Roosts	100		65	28	5	2	SI-N	N	N	Dec	N	N	N	N	SI	N	N	SI-N	SI-N	-	N	N	U	U	N	N	U	U	N	**PS**
Lagopus leucura	White-tailed Ptarmigan	100		38	41	20	1	SI	N	N	SD	N	GI	N	Inc	N	GI	N	N	SI	-	N	N	N	-	SI	N	N	N	N	**HV**
Leucosticte australis	Brown-capped Rosy-Finch	100		38	41	20	1	N	N	N	Dec	N	GI	N	N	N	GI	SI	N	SD	-	N	N	U	N	U	U	U	U	U	**HV**
Melanerpes lewis	Lewis's Woodpecker	100		65	28	5	2	N	N	N	Dec	N	N	N	N	SD	N	SD	SI-N	SD	-	N	N	U	N	U	U	U	U	U	**IL**
FISH																															
Oncorhynchus clarkii	Cutthroat Trout	100		79	19	2		GI-Inc	GI-Inc	N	SD-Dec	N	SD	SI	Inc-SI	SI	N	N	SI	N	-	N	N	SI	-	U	N	U	U	N	**HV**
MAMMALS																															
Corynorhinus townsendii pallescens	Townsend's big-eared bat	100		64	36			N	N	N	Dec	N	N	N	N	N	N	SI	N	N	-	N	U	N-SD	-	N	U	U	U	U	**PS**
Cynomys gunnisoni	Gunnison's Prairie Dog	100		40	60			N	N	N	SD	N	N	SI	N-SD	Inc-SI	N	N	N	N	-	N	N	N	-	N	N	U	U	N	**PS**
Gulo gulo	Wolverine	100		76	22	2		N	N	N	Dec	N	Inc	N	N	N	GI	SD	N	N-SD	-	N	N	U	U	U	U	U	U	U	**PS**
Lepus americanus	Snowshoe Hare	100		79	19	2		SI	N	N	SD	N	Inc	N	Inc	Inc-SI	Inc	N	N	N	-	N	N	N	-	Inc-SI	N	SI	U	N	**HV**

		Temperature Scope		Hamon AET:PET Moisture Metric Scope				Natural barriers	Anthropogenic barriers	Climate change mitigation	Dispersal/Movement	Historical thermal niche	Physiological thermal niche	Historical hydrological niche	Physiological hydrological niche	Dependence on disturbance	Dependence on Ice/snow	Restriction to geological features	Dependence on other species	Diet	Pollinator versatility	Dependence on other species for dispersal	Other species interaction	Genetic variation	Genetic bottlenecks	Phenological response	Documented response	Modeled future change	Overlap of modeled future range	Protected Areas	INDEX SCORE
Species	**English Name**	**A >5.5F**	**A 5.1F**	**< -0.119**	**- 0.119**	**- 0.096**	**- 0.073**	**B2a**	**B2b**	**B3**	**C1**	**C2ai**	**C2aii**	**C2bi**	**C2bii**	**C2c**	**C2d**	**C3**	**C4a**	**C4b**	**C4c**	**C4d**	**C4e**	**C5a**	**C5b**	**C6**	**D1**	**D2**	**D3**	**D4**	
Lynx lynx	Lynx	100		79	19	2		SI	SI	N	Dec	N	Inc-N	SI-N	SI-N	Inc-SI	Inc	N	N	Inc-SI	-	N	N	SI	-	N	N	SI	U	N	**HV**
Ochotona princeps	American pika	100		65	27	7	1	SI	N	N	SD	N	GI	N	Inc	N	SI	SI-N	N	N	-	N	U	SI	-	N	N	U	U	N	**HV**
Ovis canadensis	bighorn sheep	100		39	21	40		N	N	N	Dec	U	N	U	N-SD	N-SD	N	SI	N	N	-	N	N	U	U	U	U	U	U	U	**IL**
Sorex hoyi montanus	Pygmy Shrew	100		28		72		N	N	N	N	N	N	Inc	SI	SI-N	N	SD	N	N	-	N	N	U	U	U	U	U	U	U	**PS**
Sorex nanus	dwarf shrew	100		24	42	16	8	N	N	N	N	N	N	N	N	N	U	SD	N	N	-	N	N	U	N	U	U	U	U	U	**PS**
INSECTS																															
Boloria improba acrocnema	Uncompahgre Fritillary	100		11	89			N	N	N	SD	N	GI	SI	SI	N	N	SD	U	Inc	-	N	U	N	-	U	U	U	U	U	**HV**

APPENDIX G: Plant Species Summaries: CCVI Documentation

Author: Bernadette Kuhn, Colorado Natural Heritage Program, CSU

Plant summaries are in alphabetical order by scientific name.

Number	***Scientific Name***	**Common Name**
1.	*Aliciella sedifolia*	Stonecrop gilia
2.	*Astragalus anisus*	Gunnison milkvetch
3.	*Astragalus microcymbus*	Skiff milkvetch
4.	*Astragalus molybdenus*	Leadville Milkvetch
5.	*Boechera crandallii*	Crandall's rock cress
6.	*Botrychium echo*	reflected moonwort
7.	*Botrychium minganense*	Mingan's moonwort
8.	*Botrychium pallidum*	pale moonwort
9.	*Botrychium pinnatum*	northern moonwort
10.	*Braya glabella subsp. glabella*	arctic braya
11.	*Carex stenoptila*	Small-winged sedge
12.	*Cirsium perplexans*	Adobe thistle
13.	*Cryptantha weberi*	Weber's catseye
14.	*Draba fladnizensis*	arctic draba
15.	*Draba globosa*	rockcress draba
16.	*Draba rectifructa*	mountain whitlow-grass
17.	*Draba streptobrachia*	Colorado Divide whitlow-grass
18.	*Drosera rotundifolia*	roundleaf sundew
19.	*Erigeron humilus*	low fleabane
20.	*Erigeron lanatus*	woolly fleabane
21.	*Eriogonum coloradense*	Colorado wild buckwheat
22.	*Eriophorum altaicum var. neogaeum*	Altai cottongrass
23.	*Gilia penstemonoides*	Black Canyon gilia
24.	*Luzula subcapitata*	Colorado wood-rush
25.	*Machaeranthera coloradoensis*	Colorado tansy-aster
26.	*Penstemon mensarum*	Grand Mesa penstemon
27.	*Physaria alpina*	Avery Peak twinpod
28.	*Physaria rollinsii*	Rollins twinpod
29.	*Ranunculus gelidus*	tundra buttercup
30.	*Sullivantia hapemanii var. purpusii*	Hanging Garden sullivantia
31.	*Townsendia rothrockii*	Rothrock townsend-daisy

Thirty-one plant species of conservation concern with documented occurrences in the Gunnison Basin were assessed using the Climate Change Vulnerability Index (CCVI). This section includes two sections: 1) short summaries of each species; and 2) detailed summaries of the CCVI rankings for each species.

Note: 19 vascular and nonvascular species were added to the list following the October 26, 2011 workshop and are not included below. These additional species were qualitatively assessed for their vulnerability without the CCVI tool due to time and budgetary constraints (see Table 12 in the main report for their vulnerability scores). Vascular plants include: *Astragalus iodopetalus*, *Botrychium furcatum*, *Botrychium paradoxum*, *Carex diandra*, *Carex microglochin*, *Carex scirpoides*, *Eriophorum chamissonis*, *Eriophorum gracile*, *Hippochaete variegata*, *Hirculus prorepens*, *Kobresia simpliciuscula*, *Lomatogonium rotatum*, *Triglochin palustris*, and *Utricularia minor*. Nonvascular plants include: *Cladina arbuscula*, *Cladina rangiferina*, *Dactylina madreporiformis*, *Sphagnum angustifolium*, and *Sphagnum girgensohnii*.

No information is available for any of the plant species in the following categories: dependence on other species to generate habitat, pollinator versatility, dependence on other species for propagule dispersal and phenological response to climate change. However, these categories were often scored 'Neutral' in order to generate a CCVI score. The CCVI tool requires 8 out of 11 categories to be ranked in the Sensitivity section of the tool. If these are scored as 'Unknown', no score is generated. Thus, all ranks for each species that are 'Unknown', but were ranked as 'Neutral' in order to simply gain a score are defined below as "No data, forced score".

The thirty-one species below are known from the following ecological systems/habitats: alpine, aspen, groundwater-dependent wetlands (fens), lodgepole, low elevation sagebrush, montane grassland, montane sagebrush, montane riparian, pinyon-juniper, spruce-fir, and subalpine riparian. Nine species are known from a single ecological system/habitat, while 22 have been documented from two or three systems.

Category C2d, Dependence on Ice and Snow, was ranked as 'Increase' for all species that occur strictly in the alpine. In order to merit an 'Increase' rank, the species must be moderately dependent (50-80% of subpopulations in range) on ice or snow habitats. One exception is *Ranunculus gelidus*, a high elevation (above 12,500 feet) buttercup, which was rated 'Greatly Increase', as it is known to rely on moisture from melting snow banks. Three species below are restricted to Groundwater-dependent wetlands known as fens (*Drosera rotundifolia*, *Eriophorum altaicum* var. *neogaeum*, and *Luzula subcapitata*) were ranked as 'Increase'. Low elevation sagebrush species were rated 'Neutral', as well as lodgepole, montane grassland, montane riparian, montane sagebrush, montane shrubland, pinyon-juniper, and subalpine riparian species. 'Neutral' ranks are assigned to species that have little or no dependence on ice- or snow-associated habitats. Spruce-fir/Alpine/Aspen species were rated as 'Increase'. Any exceptions are noted below under species ranking description.

Short Summaries of Plant Species Assessed Using the CCVI Tool

1. ***Aliciella sedifolia* (Stonecrop gilia). G1/S1. FS sensitive. Family: Polemoniaceae**.

   Climate Vulnerability Score: Extremely Vulnerable. **Notes:** High elevation endemic, known globally from two sites. Rank is based on restriction to cold environments, dependence on ice and snow, and restriction to pea-sized gravels, usually of volcanic origin. **Distribution:** Extremely rare Colorado Endemic. San Juan Mountains (Hinsdale County) **Habitat:** Dry gravelly talus of tuffaceous sandstone. **Elevation:** 12000-13400 feet.

2. *Astragalus anisus* **(Gunnison milkvetch). G2G3 S2S3. BLM sensitive. Family: Fabaceae.**

Climate Vulnerability Score: Presumed Stable to Likely Increase. **Notes:** Presumed Stable or Likely to increase due to grazing, drought, and disturbance tolerance. Often found growing with *Physaria rollinsii* (see description below). **Distribution:** Colorado endemic (Gunnison and Saguache Cos.). **Habitat:** Dry gravelly flats and hillsides, in sandy clay soils overlying granitic bedrock, usually among or under low sagebrush. **Elevation:** 7500-8500 feet.

3. *Astragalus microcymbus* **(Skiff milkvetch) G1S1. BLM sensitive. Family: Fabaceae.**

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Ranked Extremely Vulnerable due to very limited occupied habitat, restriction to specific geologic substrates. Species is also somewhat restricted to cool climates. Candidate for listing under the Endangered Species Act. Migration is unlikely and therefore adaptation is critical. **Distribution:** Colorado endemic (South Beaver Creek, Gunnison Co.). **Habitat:** Open sagebrush or juniper-sagebrush communities on moderately steep to steep slopes. Often found in rocky areas with a variety of soil conditions from clay to cobbles, gray to reddish in color. **Elevation:** 7600-8400 feet.

4. *Astragalus molybdenus* **(Leadville milkvetch). G3/S2. FS sensitive. Family: Fabaceae.**

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is based on restriction to cold environments, dependence on ice and snow, and requirement of nodulization. Diminutive, high alpine milkvetch that resembles *Astragalus alpinus*. **Distribution:** Colorado endemic (Lake, Park, Pitkin and Summit Cos.). **Habitat:** Rocky slopes and turf hillsides above timberline. Usually found on limestone. **Elevation:** 11400-13200 feet.

5. *Boechera crandallii* **(Crandall's rockcress). G2/S2. BLM sensitive. Family: Brassicaceae.**

Climate Vulnerability Score: Highly Vulnerable. **Notes:** Rank is based on anthropogenic barriers that exist in known populations. Also, this species is restricted to cool or cold environments that are considered vulnerable to climate change. Globally rare, but often locally abundant in the Gunnison Basin.

6. *Botrychium echo* **(reflected moonwort). G3/S3. FS sensitive. Family: Ophioglossaceae.**

Climate Vulnerability Score: Moderately Vulnerable. **Notes:** Considered Moderately Vulnerable due to restriction to somewhat cool or cold environments, potential loss of habitat due to sedimentation resulting from timber harvest or forest fires, and mycorrhizae requirement for establishment. Poorly documented in Gunnison Basin. Often found growing with other Botrychium species. **Distribution:** N Arizona, N Utah and Colorado (Boulder, Clear Creek, Conejos, El Paso, Grand, Gilpin, Gunnison, Lake, Larimer, Park, San Juan and Teller Cos.). **Habitat:** Gravelly soils, rocky hillsides, grassy slopes, and meadows. **Elevation:** 9500-11000 feet.

7. *Botrychium minganense* **(Mingan's moonwort). G4/S2. FS sensitive. Family: Ophioglossaceae**

Climate Vulnerability Score: Moderately Vulnerable. **Notes:** Considered Moderately Vulnerable due to restriction to somewhat cool or cold environments, potential loss of habitat due to sedimentation resulting from timber harvest or forest fires, and mycorrhizae requirement for establishment. Poorly documented in Gunnison Basin. Often found growing with other Botrychium species. **Distribution:** Among the most widespread and abundant moonworts occurring across the United States and Canada, occurring primarily in northern latitudes and at high elevations to the south **Habitat:** Varies widely from dense forest to open meadow and from summer-dry meadows to permanently saturated fens and seeps. **Elevation:** 4000-6700 feet.

8. *Botrychium pallidum* (pale moonwort). G3/S2. FS sensitive. Family: Ophioglossaceae

Climate Vulnerability Score: Moderately Vulnerable. **Notes:** Considered Moderately Vulnerable due to restriction to somewhat cool or cold environments, potential loss of habitat due to sedimentation resulting from timber harvest or forest fires, and mycorrhizae requirement for establishment. Poorly documented in Gunnison Basin. Often found growing with other Botrychium species. **Distribution:** S Canada, Maine, Michigan and Colorado (Boulder, Conejos, Gunnison, Larimer, Park, San Juan and Teller Cos.). **Habitat:** Open exposed hillsides, burned or cleared areas, old mining sites. **Elevation:** 9800-10600 feet.

9. *Botrychium pinnatum* (northern moonwort). G4?/S1. FS sensitive. Family: Ophioglossaceae.

Climate Vulnerability Score: Moderately Vulnerable. **Notes:** Considered Moderately Vulnerable due to restriction to somewhat cool or cold environments, potential loss of habitat due to sedimentation resulting from timber harvest or forest fires, and mycorrhizae requirement for establishment. Poorly documented in Gunnison Basin. **Distribution:** widely throughout western North America from high elevations in northern California, northern Nevada, northern Arizona, Utah and Colorado (Mineral and San Juan Cos.) to near sea level in Alaska and northwestern Canada. However, it is rare throughout its range. **Habitat:** Most commonly found in moist grassy sites in open forests and meadows. Often occurring near streams and other sites where soil moisture is constant. **Elevation:** 1900-7300 feet.

10. *Braya glabella* ssp. *glabella* (artic braya). G5TNR/S1. FS sensitive. Family: Brassicaceae

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is based on restriction to cold environments, dependence on ice and snow, and restriction to calcareous substrates. Circumboreal species. Listed as Sensitive by the U.S. Forest in Region 2. **Distribution:** Alaska, Yukon, British Columbia, Northwest Territories, Quebec. Disjunct in central Colorado (Chaffee, Gunnison, Park and Pitkin Cos.). **Habitat:** Calcareous substrates, especially Leadville Limestone; sparsely vegetated slopes above timberline with fine gravels or on disturbed sites associated with inactive mines. **Elevation:** 12000-13000 feet.

11. *Carex stenoptila* (small-winged sedge). G2/S2. Family: Cyperaceae.

Climate Vulnerability Score: Highly Vulnerable. **Notes:** Ranked as Highly Vulnerable due to *C. stenoptila* is found in moist to wet shaded areas along streams and rivers in the Gunnison Basin. Climate models project earlier, faster snowmelt along with decreased summer precipitation resulting in significantly lower amounts of water stored in soils in the summer (Barsugli 2010). These conditions could lead to a decline in habitat for *C. stenoptila*. Likely overlooked due to its resemblance to *Carex microptera*. **Distribution:** Montana (Flathead and Ravalli Cos. Yellowstone National Park), Wyoming (Big Horn, Carbon, Johnson, and Park Cos.), and Colorado (Grand, Montrose, Park, and Routt Cos.). **Habitat:** Dry, often rocky soil of grasslands and open forests in the montane and subalpine zones, and moist soil along streams in the valleys. **Elevation:** 7800-9500 feet.

12. ***Cirsium perplexans* (Adobe thistle). G2G3/S2S3. FS sensitive. Family: Asteraceae**

    Climate Vulnerability Score: Presumed Stable. **Notes:** Presumed Stable due to preference for highly disturbed areas and long distance dispersal capability. Likely to be removed from CNHP tracking list due to high number of reported occurrences and need for disturbance. Often found at low quality sites along powerlines and dirt roads. **Distribution:** Colorado (Delta, Garfield, Gunnison, Mesa, Montrose, and Ouray Cos.). **Habitat:** Found almost exclusively on clay soils or "adobe hills" (local Colorado term for barren outcrops of clay soils) derived from shales of the Mancos or Wasatch formations. **Elevation:** 5000-7600 feet.

13. **Cryptantha weberi (Weber's catseye). G3/S3. Family: Boraginaceae**

    Climate Vulnerability Score: Presumed Stable. **Notes:** Presumed Stable due to lack of specific habitat requirements. **Distribution:** Colorado (Conejos, Hinsdale, Mineral, Rio Grande, and Saguache Cos.). **Habitat:** Found in rocky soil, often with sagebrush. **Elevation:** 7700-9500 feet.

14. ***Draba fladnizensis* (artic draba). G4/S2S3. Family: Brassicaceae**

    Climate Vulnerability Score: Highly Vulnerable. **Notes:** Rank is based on restriction to cold environments, inability for long distance seed dispersal, and dependence on ice and snow. **Distribution:** Alaska to Greenland. It extends south in the Rocky Mountains to Colorado and Utah. Also occurs in Eurasia. **Habitat:** Rock outcrops and talus, alpine meadows, sandy gravel. **Elevation:** 10700-14000 feet.

15. ***Draba globosa* (rockcress draba). G3/S1. Family: Brassicaceae.**

    Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is based on restriction to cold environments, inability for long distance seed dispersal, and dependence on ice and snow. **Distribution:** Wyoming, Utah, Montana and central Colorado (Gunnison and Lake Cos.). **Habitat:** Alpine meadows, granitic talus slopes, rock crevices. **Elevation:** 11500-12500 feet.

16. ***Draba rectifructa* (mountain whitlow-grass). G3?/S2. Family: Brassicaceae.**

    Climate Vulnerability Score: Increase Likely. **Notes:** Rank is based on tolerance for broad moisture and climate regime. **Distribution:** Arizona, Colorado, New Mexico, and Utah. **Habitat:** Found in open forests, meadows, and on open slopes. **Elevation:** 7300-9500 feet.

17. ***Draba streptobrachia* (Colorado Divide whitlow-grass). G3/S3. Family: Brassicaceae.**

    Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is based on restriction to cold environments, inability for long distance seed dispersal, and dependence on ice and snow. **Distribution:** Colorado (Alamosa, Clear Creek, Conejos, Grand, Hinsdale, Jackson, Larimer, Lake, La Plata, Mineral, Park, Pitkin, Rio Grande, and San Juan Cos.). **Habitat:** Alpine tundra, scree, ridges, and alpine slopes. Turf, fellfields, talus slopes, crevices in rock ledges, and loose soils. **Elevation:** 10500-13200 feet.

18. *Drosera rotundifolia* (roundleaf sundew). G5/S2. FS sensitive. Family: Droseraceae.

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is due to restriction to fens and lack of genetic diversity. Although fens treated as a plant community were ranked "Low" for vulnerability, individual species within the fen often occur on the margins, and are likely susceptible to small changes in the alteration of hydrology. **Distribution:** Eurasia; NE United States and Canada; south to Idaho, Montana, California, Nevada, Florida and Colorado (Grand, Gunnison and Jackson Cos.). **Habitat:** Floating peat mats and on the margins of acidic ponds and fens. **Elevation:** 9100-9800 feet.

19. *Erigeron humilis* (low fleabane). G4/S1. Family: Asteraceae.

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is based on restriction to cold environments and dependence on ice and snow. **Distribution:** Canada, Montana, Idaho, Wyoming, Utah, and Colorado (Gunnison, Hinsdale, Pitkin, and San Juan Cos.). **Habitat:** Arctic and alpine tundra, snow bed slopes, pond and stream margins, boulder ridges in streambeds, heaths, ledges, dry gravelly slopes. **Elevation:** 12000-14000 feet.

20. *Erigeron lanatus* (woolly fleabane). G3G4/S1. FS sensitive. Family: Asteraceae.

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is based on restriction to cold environments, inability for long distance seed dispersal, and dependence on ice and snow. **Distribution:** British Colombia, S Alberta, NW Montana. Disjunct in Wyoming and Colorado (Chaffee, Gunnison and Pitkin Cos.). **Habitat:** Steep alpine scree and talus slopes. **Elevation:** 12500-13500 feet.

21. *Eriogonum coloradense* (Colorado wild buckwheat). G2/S2. BLM sensitive. Family: Polygonaceae.

Climate Vulnerability Score: Highly Vulnerable. **Notes:** Ranked as Highly Vulnerable due to restriction to cold environments and dependence on snow cover. Species did not score as Extremely Vulnerable due to its broader elevation range, and broad substrate requirements. **Distribution:** Endemic to Colorado (Gunnison, Park, Pitkin and Saguache Cos.). **Habitat:** Gravelly or sandy soil, often subalpine and alpine slopes, some-times montane grasslands. **Elevation:** 8500-12500 feet.

22. *Eriophorum altaicum* var. *neogaeum* (Altai cottongrass). G4?T3T4/S3. FS sensitive. Family: Cyperaceae.

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Extremely Vulnerable based on restriction to high elevation fens. Although fens treated as a plant community were ranked "Low" for vulnerability, individual species within the fen often occur on the margins, and are likely susceptible to small changes in the alteration of hydrology. **Distribution:** Alaska, British Columbia, Uinta Mountains in Utah, and Colorado (Eagle, Park and San Juan, San Miguel, and Saguache Cos.). **Habitat:** Fens. **Elevation:** 9500-14000 feet.

23. *Gilia penstemenoides* (Black Canyon gilia). G3/S3. FS sensitive. Family: Polemoniaceae.

Climate Vulnerability Score: Moderately Vulnerable. **Notes:** Species is Moderately Vulnerable due to restriction to cliffs. Also, significant barriers to dispersal include the Black Canyon. **Distribution:** Colorado endemic (Gunnison, Hinsdale, Mineral and Montrose Cos.). **Habitat:** Cracks on vertical walls, narrow ledges and cliff rims. Grows in gneiss, schist, and shale. **Elevation:** 6800-9000 feet.

24. ***Luzula subcapitata*** **(Colorado wood-rush). G3?/S3?. Family: Juncaceae.**

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Extremely Vulnerable based on restriction to high elevation fens. Although fens treated as a plant community were ranked "Low" for vulnerability, individual species within the fen often occur on the margins, and are likely susceptible to small changes in the alteration of hydrology. **Distribution:** Colorado endemic (Boulder, Chaffee, Clear Creek, Eagle, Gilpin, Grande, Gunnison, Lake, Larimer, Pitkin, San Juan, and Summit Cos.). **Habitat:** Subalpine and alpine bogs. **Elevation:** 10500-12200 feet.

25. ***Machaeranthera coloradoensis*** **(Colorado tansy-aster). G3/S3. FS sensitive. Family: Asteraceae.**

Climate Vulnerability Score: Presumed Stable. **Notes:** Presumed Stable due to capability for long distance seed dispersal. Species is known to occur on a very wide range of substrates. Also, species is likely adapted to a broad moisture and temperature regime. **Distribution:** Endemic to SC Wyoming and Colorado (Gunnison, Hinsdale, La Plata, Lake, Mineral, Park, Pitkin, Saguache and San Juan Cos.). **Habitat:** Gravelly areas in mountain parks, slopes, and rock outcrops up to dry tundra. **Elevation:** 8500-12500 feet.

26. ***Penstemon mensarum*** **(Grand Mesa penstemon). G3/S3. Family: Plantaginaceae**

Climate Vulnerability Score: Presumed Stable. **Notes:** Presumed Stable due to preference for highly disturbed areas. Species is likely adapted to a broad moisture and temperature regime. **Distribution:** Endemic to Colorado (Delta, Gunnison, and Mesa Cos.). **Habitat:** Found in meadows, spruce-fir forests, and oak forests. **Elevation:** 7400-10200 feet.

27. ***Physaria alpina*** **(Avery Peak twinpod). G2/S2. Family: Brassicaceae**

Climate Vulnerability Score: Extremely vulnerable. **Notes:** Rank is based on restriction to cold environments and dependence on ice and snow. **Distribution:** Endemic to Colorado (Gunnison, Lake, Park, and Pitkin Cos.). **Habitat:** Found in rocky alpine tundra. **Elevation:** 11400-13500 feet.

28. ***Physaria rollinsii*** **(Rollins twinpod). G2/S2. Family: Brassicaceae**

Climate Vulnerability Score: Presumed stable. **Notes:** Presumed Stable or Likely to increase due to grazing, drought, and disturbance tolerance. Often found growing with *Astragalus anisus* (see description above). **Distribution:** Endemic to Colorado (Gunnison, Mesa, and Pitkin Cos.). **Habitat:** Found on dry hillsides and rocky ridges, in sagebrush. **Elevation:** 7500-8700 feet.

29. ***Ranunculus gelidus*** **(tundra buttercup). G4G5/S3S4. Family: Ranunculaceae.**

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is based on restriction to cold environments and dependence on ice and snow. Documented occurrences are located on the edge of melting snowbanks. **Distribution:** Eastern Siberia, Alaska, south to Montana and Colorado (Boulder, Chaffee, Clear Creek, Gunnison, Hinsdale, Lake, Park and Summit Cos.). **Habitat:** Among rocks and scree on exposed summits, slopes. **Elevation:** 12000-14100 feet.

30. ***Sullivantia hapemanii*** **var.** ***purpusii*** **(Hanging Garden sullivantia). G3T3/S3. Family: Saxifragaceae.**

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Rank is due to species' narrow ecological amplitude, general restriction to limestone, and habit fragility (seeps, springs, and streamsides). **Distribution:** Colorado endemic (Garfield, Gunnison, Montrose, Pitkin and Rio Blanco Cos.). **Habitat:** Hanging gardens, wet cliffs of various geology including lime-stone, shale, and quartzite. **Elevation:** 7000-10000 feet.

31. ***Townsendia rothrockii*** **(Rothrock townsend-daisy). G2G3/S2S3. Family: Asteraceae**

Climate Vulnerability Score: Extremely Vulnerable. **Notes:** Perennial forb known from a variety of substrates including limestone, sandstone and volcanic substrates. **Distribution:** Colorado in counties southwest of Summit Co. as well as New Mexico. **Habitat:** Found in dry, open places in rocky soil, especially alpine fell fields. **Elevation:** 8000-13500 feet.

Detailed Summaries for Plant Species Assessed Using the CCVI Tool

1. Stonecrop gilia (*Aliciella sedifolia*)

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Occurs above 11,800 feet, so could still shift upward in elevation.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral. No data, forced score.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No Data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine above 11,800 ft. (Anderson 2004).

C3) Restriction to uncommon geological features or derivatives. Somewhat Increase. Known from cobbly volcanic rock (Hogan 2007; Anderson 2004).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Unknown.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

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2. **Gunnison milkvetch (*Astragalus anisus*)**

Ecological System/Habitat: Low elevation sagebrush

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral**.**

B3) Impact of land use changes resulting from human responses to climate change. Neutral.

C1) Dispersal and movements. Neutral. No data, forced score.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Somewhat Decrease. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral. Based on field observations, this plant is well adapted to drought and temperature extremes (Johnston, pers. comm. 2011).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Increase. The species has experienced **small (4-10 inches/100-254 mm)** precipitation variation in the past 50 years. Data from the Cochetopa Creek weather station (adjacent to a known *A. anisus* occurrences, 8,000 feet) shows total monthly precipitation ranging from 6.8 to 17.78 inches (Colorado Climate Trends 2011).

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Neutral. Species has little dependence on a strongly seasonal hydrologic regime or localized moisture regime that is highly vulnerable to loss or reduction with climate change. Precipitation amounts are fairly evenly distributed throughout the seasons, with somewhat more moisture occurring during the "monsoon" season of July and August (Decker and Anderson 2004).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Somewhat Increase. Although *Astragalus anisus* has not been investigated for nodulization. However, nodules have been reported for several other species in the subgroup Argophylii (*A. crassicarpus*, *A. missouriensis*, *A. mollissimus*, and *A. purshii*), so it is possible that *A. anisus* also possesses this ability (Decker and Anderson 2004).

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

<u>Literature Cited</u>

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Colorado Climate Trends. 2011. Total Annual Precipitation Historic Data from Cochetopa Creek weather station. http://climatetrends.colostate.edu/. Accessed June 6, 2011.

Decker, K. and D.G. Anderson. (2004, April 21). *Astragalus anisus* M.E. Jones (Gunnison milkvetch): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/astragalusanisus.pdf. [May 5, 2011].

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3. **Skiff milkvetch (*Astragalus microcymbus*)**

Ecological System/Habitat: Low elevation sagebrush

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Somewhat Increase**.** The following potential factors that may affect the habitat or range of *Astragalus microcymbus* are (1) Residential and urban development; (2) recreation, roads, and trails; (3) utility corridors; (4) nonnative invasive plants; (5) wildfire; (6) contour plowing and nonnative seedings; (7) livestock, deer and elk use of habitat; (8) mining, oil and gas leasing; (9) climate change; and (10) habitat fragmentation and degradation (USFWS 2010).

B3) Impact of land use changes resulting from human responses to climate change. Somewhat Increase. Under certain climate conditions there may be more pressure to graze intensely.

C1) Dispersal and movements. Unknown.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Somewhat Decrease. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat Increase. Species is somewhat restricted to cool or cold environments that may be lost as a result of climate change. Temperatures in the *Astragalus microcymbus* occupied habitat can dip below freezing any month of the year. Climate models predict earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Increase. The species has experienced **small (4-10 inches/100-254 mm)** precipitation variation in the past 50 years. Data from the Cochetopa Creek weather station (approx. 9 air mi E of known *A. microcymbus* occurrence) shows total monthly precipitation ranging from 6.8 to 17.78 inches (Colorado Climate Trends 2011).

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Increase. Precipitation also influences fruit production in *A. microcymbus* with additional fruit produced with additional rain (Denver Botanic Gardens 2008).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little known dependence on snow or ice cover.

C3) Restriction to uncommon geological features or derivatives. Somewhat Increase. Geologically, *A. microcymbus* is associated with: (1) Felsic and hornblendic gneiss (metamorphic from igneous) substrates; (2) granitic (igneous) rocks of 1,700 million-year age group; and (3) biotitic gneiss, schist, and migmatite (sedimentary) substrates with 52, 37, and 11 percent, respectively, in each geology (USFWS 2010). The areas where *Astragalus microcymbus* is found are generally distinct from surrounding habitats. They are more sparsely vegetated, drier than surrounding areas, more heavily occupied by cacti, and appear to have some specific soil properties as described above. This habitat is limited and has a patchy distribution on the landscape (USFWS 2010).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.
C4e) Forms part of an interspecific interaction not covered by C4a-d. Increase. Although *A. microcymbus* has not been studied for nodulization, many species of *Astragalus* form mycorrhizal associations.
C5) Genetic factors. Unknown.
C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

<u>Literature Cited</u>

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

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4. **Leadville Milkvetch (*Astragalus molybdenus*)**

Ecological System/Habitat: Alpine
B1) Exposure to sea level rise. Neutral.
B2a) Distribution relative to natural barriers. Increase. Occurs above 9,500 feet, with most occurrences above 11,000 feet, so could still shift upward in elevation (Ladyman 2003).
B2b) Distribution relative to anthropogenic barriers. Neutral**.**
B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Increase. This species is likely a good disperser, as it currently occupies nearly all suitable habitats but is likely limited by germination (Johnston, pers. comm. 2011).
C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.
C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (upper subalpine/alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.
C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the

lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine typically above 11,000 ft. Specific areas where patches of plants are often described are areas with late snow-melt or with persistent snowdrifts (Ladyman 2003).

C3) Restriction to uncommon geological features or derivatives. Increase. *Astragalus molybdenus* has been reported to occur specifically on Lower Ordovician Manitou dolomite and Leadville limestone geological formations but may be found on others (Ray 2001, USDA Forest 17 Service 1995b, Rossignol, personal communication 2002).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Unknown.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Increase. Roots are likely to form a mycorrhizal association (Ladyman 2004).

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

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USDA Forest Service. 1995b. Establishment of Hoosier Ridge Research Natural Area. Decision notice/designation order and finding of no significant impact. Unpublished document. Prepared by South Park Ranger District, Pike and San Isabel National Forest and Dillon Ranger District, Arapahoe and Roosevelt National Forests (administered by White River National Forest), CO.

5. Crandall's rockcress (*Boechera crandallii*)

Ecological System/Habitat: Low elevation sagebrush

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Increase**.** Known populations are likely to be subject to high levels of disturbance from both hiking and off-road vehicle (ORV) recreation, the latter of which has become increasing popular and includes all-terrain vehicles (ATVs), dirt bikes, and four-wheel drive vehicles. Snowmobiles are also used within the range of *B. crandallii* (Ladyman 2005).

B3) Impact of land use changes resulting from human responses to climate change. Somewhat Increase. Under certain climate conditions there may be more pressure to graze intensely. Geothermal development has the potential to impact 15% **-** 20% of this species' habitat within the Gunnison Basin.

C1) Dispersal and movements. Neutral. No data, forced score.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Somewhat Decrease. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat Increase. Species is somewhat restricted to cool or cold environments that may be lost as a result of climate change. Temperatures in the *Boechera crandallii* occupied habitat can dip below freezing any month of the year. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Increase. The species has experienced **small (4-10 inches/100-254 mm)** precipitation variation in the past 50 years. Data from the Cochetopa Creek weather station (adjacent to known *A. anisus* occurrences) shows total monthly precipitation ranging from 6.8 to 17.78 inches (Colorado Climate Trends 2011).

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Neutral. Species has little dependence on a strongly seasonal hydrologic regime or localized moisture regime that is highly vulnerable to loss or reduction with climate change.

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover.

C3) Restriction to uncommon geological features or derivatives. Neutral. No data, forced score.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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6. **Reflected moonwort (*Botrychium echo*)**

Ecological System/Habitat: Spruce-fir, Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral**.**

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Increase. Dispersal of Botrychium spores probably occurs over short distances via gravity (Beatty et al. 2003).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. This species has experienced slightly lower than average (47.1-57°F/26.3-31.8°C) temperature variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat Increase. Species is somewhat (10-50% of range) restricted to relatively cool or cold environments (upper subalpine/alpine).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'. Elevations of known *B. echo* occurrences in Colorado range from 8,500-12,000 feet.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Somewhat Increase. Potential sedimentation following timber harvest and/or fires could lead to a loss of habitat for *Botrychium* species. Fire suppression could also lead to a loss of habitat (Anderson and Cariveau 2004).

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Snow cover and ice have not been documented as important element of *B. echo* habitat.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4a) Dependence on other species to generate habitat. Neutral.

C4c) Pollinator Versatility. Neutral. Does not require pollinators; disperses spores by wind and water.

C4d) Dependence on other species for propagule dispersal. Neutral.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Somewhat Increase. Mycorrhizae may be the most important factor for establishment, distribution, and abundance of Botrychium species (Johnson-Groh 1998, Johnson-Groh 1999).

C5) Genetic factors. Neutral. Findings suggest that low genetic variability and homozygosity may not be a negative attribute for the persistence of Botrychium, either at the species or population level (Kolb and Spribille 2001).

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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7. **Mingan's moonwort (*Botrychium minganense*)**

Ecological System/Habitat: Spruce-fir, Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Increase. Dispersal of Botrychium spores probably occurs over short distances via gravity (Beatty et al. 2003).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. This species has experienced slightly lower than average (47.1-57°F/26.3-31.8°C) temperature variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat Increase. Species is somewhat (10-50% of range) restricted to relatively cool or cold environments (upper subalpine/alpine).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'. Elevations of known *B. minganense* occurrences in Colorado range from 9,000-12,000 feet.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Somewhat Increase. Potential sedimentation following timber harvest and/or fires could lead to a loss of habitat for Botrychium species. Fire suppression could also lead to a loss of habitat (Anderson and Cariveau 2004).

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Snow cover and ice have not been documented as important element of *B. minganense* habitat.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4a) Dependence on other species to generate habitat. Neutral.

C4c) Pollinator Versatility. Neutral. Does not require pollinators; disperses spores by wind and water.

C4d) Dependence on other species for propagule dispersal. Neutral.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Somewhat Increase. Mycorrhizae may be the most important factor for establishment, distribution, and abundance of Botrychium species (Johnson-Groh 1998, Johnson-Groh 1999).

C5) Genetic factors. Neutral. Findings suggest that low genetic variability and homozygosity may not be a negative attribute for the persistence of Botrychium, either at the species or population level (Kolb and Spribille 2001).

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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8. **Pale moonwort (*Botrychium pallidum*)**

Ecological System/Habitat: Spruce-fir, Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral**.**

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Increase. Dispersal of Botrychium spores probably occurs over short distances via gravity (Beatty et al. 2003).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. This species has experienced slightly lower than average (47.1-57°F/26.3-31.8°C) temperature variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewha**t** Increase. Species is somewhat (10-50% of range) restricted to relatively cool or cold environments (upper subalpine/alpine).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'. Elevations of known *B. pallidum* occurrences in Colorado range from ca. 9,000-12,000 feet.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Somewhat Increase. Potential sedimentation following timber harvest and/or fires could lead to a loss of habitat for Botrychium species. Fire suppression could also lead to a loss of habitat (Anderson and Cariveau 2004).

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Snow cover and ice have not been documented as important element of *B. pallidum* habitat.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4a) Dependence on other species to generate habitat. Neutral.

C4c) Pollinator Versatility. Neutral. Does not require pollinators; disperses spores by wind and water.
C4d) Dependence on other species for propagule dispersal. Neutral.
C4e) Forms part of an interspecific interaction not covered by C4a-d. Somewhat Increase. Mycorrhizae may be the most important factor for establishment, distribution, and abundance of Botrychium species (Johnson-Groh 1998, Johnson-Groh 1999).
C5) Genetic factors. Neutral. Findings suggest that low genetic variability and homozygosity may not be a negative attribute for the persistence of Botrychium, either at the species or population level (Kolb and Spribille 2001).
C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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9. **Northern moonwort (*Botrychium pinnatum*)**
Ecological System/Habitat: Spruce-fir, Alpine
B1) Exposure to sea level rise. Neutral.
B2a) Distribution relative to natural barriers. Neutral.
B2b) Distribution relative to anthropogenic barriers. Neutral**.**
B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Increase. Dispersal of Botrychium spores probably occurs over short distances via gravity (Beatty et al. 2003).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. This species has experienced slightly lower than average (47.1-57°F/26.3-31.8°C) temperature variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat Increase. Species is somewhat (10-50% of range) restricted to relatively cool or cold environments (upper subalpine/alpine).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'. Elevations of known *B. pinnatum* occurrences in Colorado range from 10,000-12,000 feet.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi). It is primarily found in mesic meadows, subalpine meadows, and forested streambanks (Legler 2010).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Somewhat Increase. Potential sedimentation following timber harvest and/or fires could lead to a loss of habitat for Botrychium species. Fire suppression could also lead to a loss of habitat (Anderson and Cariveau 2004).

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Snow cover and ice have not been documented as important element of *B. pinnatum* habitat.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4a) Dependence on other species to generate habitat. Neutral.

C4c) Pollinator Versatility. Neutral. Does not require pollinators; disperses spores by wind and water.

C4d) Dependence on other species for propagule dispersal. Neutral.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Somewhat Increase. Mycorrhizae may be the most important factor for establishment, distribution, and abundance of Botrychium species (Johnson-Groh 1998, Johnson-Groh 1999).

C5) Genetic factors. Neutral. Findings suggest that low genetic variability and homozygosity may not be a negative attribute for the persistence of Botrychium, either at the species or population level (Kolb and Spribille 2001).

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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10. **Arctic braya (*Braya glabella subsp. glabella*)**
Ecological System/Habitat: Alpine
B1) Exposure to sea level rise. Neutral.
B2a) Distribution relative to natural barriers. Increase. Occurs above 11,400 feet in Colorado, so could still shift upward in elevation (Moore et al. 2006).
B2b) Distribution relative to anthropogenic barriers. Neutral**.**
B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Increase. This species is likely a poor disperser (Johnston, pers. comm. 2011; Moore et al. 2006). Plants grow low to the ground and seed likely falls locally and washes downhill (Neely 2011, pers. comm.).
C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.
C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (upper subalpine/alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer

precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine typically above 11,000 ft (Moore et al. 2006).

C3) Restriction to uncommon geological features or derivatives. Increase. *Braya glabella* ssp. *glabella* occupies limestone barrens characterized by coarse, shallow calcareous soils, including disturbed areas with loose limestone gravel (Moore et al. 2006).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Unknown. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown. No data, forced score.

C5) Genetic factors. Increase. Lack of genetic diversity has been identified as a conservation issue for *B. glabella* subsp. *glabella* (Moore et al. 2006).

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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11. Small-winged sedge (*Carex stenoptila*)

Ecological System/Habitat: Subalpine riparian

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Increase. Dispersal distances are unknown for *C. stenoptila*, but wind, water and animals may be vectors.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral to Somewhat Increase. Species is somewhat (10-50% of range) restricted to relatively cool or cold environments (montane).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Increase. The species has experienced **small (4-10 inches/100-254 mm)** precipitation variation in the past 50 years. Data from the Cochetopa Creek weather station (adjacent to known *A. anisus* occurrences) shows total monthly precipitation ranging from 6.8 to 17.78 inches (Colorado Climate Trends 2011).

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Increase. *C. stenoptila* is found in moist to wet shaded areas along streams and rivers in the Gunnison Basin. Climate models project earlier, faster snowmelt along with decreased summer precipitation resulting in significantly lower amounts of water stored in soils in the summer (Barsugli 2010). These conditions could lead to a decline in habitat *for C. stenoptila*.

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. Likely wind pollinated.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

<u>Literature Cited</u>

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Colorado Climate Trends. 2011. Total Annual Precipitation Historic Data from Cochetopa Creek weather station. http://climatetrends.colostate.edu/. Accessed June 6, 2011.

12. **Adobe thistle (*Cirsium perplexans*)**

Ecological System/Habitat: Low elevation sagebrush, Pinyon-Juniper

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Somewhat Increase. Under certain climate conditions there may be more pressure to graze intensely.

C1) Dispersal and movements. Somewhat Decrease. Dispersal distances are unknown for *C. perplexans*, but seeds of Asteraceae are capable of long distance wind dispersal.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral. Species is not significantly affected by thermal characteristics of the environment in the assessment area, or species occupies habitats that are known to be less vulnerable to projected climate change.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Neutral. The species has experienced **average (21-40 inches/509-1,016 mm)** precipitation variation in the past 50 years. Data from the Cimarron weather station (nearest to known *C. perplexans* core habitat and occurrences) shows total monthly precipitation ranging from 5.8 to 30.05 inches (Colorado Climate Trends 2011).

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Neutral. *C. perplexans* has no documented dependence on a strongly seasonal hydrologic regime.

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover.

C3) Restriction to uncommon geological features or derivatives. Somewhat Increase. Known from clay soils derived from the Wasatch and Mancos Formations (Panjabi and Anderson 2004).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Colorado Climate Trends. 2011. Total Annual Precipitation Historic Data from Cochetopa Creek weather station. http://climatetrends.colostate.edu/. Accessed June 6, 2011.

Panjabi, S.S. and D.G. Anderson. 2004. *Cirsium perplexans* (Rydb.) Petrak (Rocky Mountain thistle): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/cirsiumperplexans.pdf . [Accessed October 6, 2011].

13. **Weber's catseye (*Cryptantha weberi*)**

Ecological System/Habitat: Montane sagebrush

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral. Occurrences in the Gunnison Basin are located in sagebrush habitats ranging from 8,900-9,400 feet.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral. Species is not significantly affected by thermal characteristics of the environment in the assessment area, or species occupies habitats that are thought to be not vulnerable to projected climate change.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'. Although the station is 500 feet above the highest documented site for *C. weberi*, it is the best available data source for this area.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Neutral. *C. weberi* has no documented dependence on a strongly seasonal hydrologic regime.
C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.
C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. No dependence on ice or snow cover has been documented for *C. weberi*.
C3) Restriction to uncommon geological features or derivatives. Increase. Is known to occur on tuffaceous sands (Johnston pers. comm. 2011).
C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.
C4c) Pollinator Versatility. Neutral. No data, forced score.
C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.
C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.
C5) Genetic factors. Unknown.
C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Johnston, B. 2011. Personal communication at Gunnison Climate Change Workshop, May 13, 2011. Gunnison, Colorado.

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

14. **Arctic draba (*Draba fladnizensis*)**

Ecological System/Habitat: Spruce-fir, Aspen, Alpine
B1) Exposure to sea level rise. Neutral.
B2a) Distribution relative to natural barriers. Increase and Somewhat Increase. Occurs in the upper subalpine and alpine from 11,000-14,000 ft.
B2b) Distribution relative to anthropogenic barriers. Neutral.
B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Somewhat Increase. Dispersal of tiny Draba seeds through boulder and scree is likely to occur over very small distances.
C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.
C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (upper subalpine/alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer

precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine above 11,000 ft.

C3) Restriction to uncommon geological features or derivatives. Neutral. Known to occur on a range of substrates in the alpine.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Unknown.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

15. **Rockcress draba (*Draba globosa*)**

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Restricted to the alpine in the Gunnison Basin, with one known occurrence at 12,650 feet.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Somewhat Increase. Dispersal of tiny Draba seeds through boulder and scree is likely to occur over very small distances.
C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.
C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (upper subalpine/alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.
C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.
C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).
C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.
C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine above 12,500 ft.
C3) Restriction to uncommon geological features or derivatives. Neutral. Known to occur on both granite and limestone in the alpine (Ladyman 2004).
C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.
C4c) Pollinator Versatility. Neutral. No data, forced score.
C4d) Dependence on other species for propagule dispersal. Unknown. No data, forced score.
C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.
C5) Genetic factors. Somewhat Increase. Measured genetic diversity is rated as 'Somewhat Increase' based on the following statement from Ladyman 2004 "it is likely that the most geographically separated populations will have the greatest genetic divergence and a significant loss of genetic diversity will likely result if populations at the edge of the range or in obviously disjunct localities, such as those in Colorado in Region 2, are lost."
C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Ladyman, J.A.R. 2004. Draba globosa Payson (beavertip draba): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. [Online] http://www.fs.fed.us/r2/projects/scp/assessments/drabaglobosa.pdf [Accessed July 1, 2011].

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

16. Mountain whitlow-grass (*Draba rectifructa*)

Ecological System/Habitat: Lodgepole

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Somewhat Increase. Dispersal of tiny Draba seeds through montane habitats is likely to occur over very small distances.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Somewhat Decrease. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years (Colorado Climate Trends 2011).

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'. Although the station is higher in elevation than known *Draba rectifructa* habitat (8,000-9,600 ft), it offers the best available climate data in the area.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover.

C3) Restriction to uncommon geological features or derivatives. Neutral. Known to occur in sagebrush openings in lodgepole pine forests in the Gunnison Basin.

C4a) Dependence on other species to generate habitat. Unknown.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Colorado Climate Trends. 2011. Total Annual Precipitation Historic Data from Cochetopa Creek weather station. http://climatetrends.colostate.edu/. Accessed June 6, 2011.

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

17. **Colorado Divide whitlow-grass (*Draba streptobrachia*)**

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Restricted to the alpine in the Gunnison Basin, with one known occurrence at 11,500 feet.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Somewhat Increase. Dispersal of tiny Draba seeds through boulder and scree is likely to occur over very small distances.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (upper subalpine/alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine above 12,500 ft.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Unknown.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

<u>**Literature Cited**</u>

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

18. Roundleaf sundew (*Drosera rotundifolia*)

Ecological System/Habitat: Groundwater-dependent wetlands (fens)

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Somewhat Increase. The one occurrence in the Gunnison Basin occurs between 9,500 and 9,700 feet, and it is surrounded by high mountains.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Somewhat Increase. Dispersal (C1) was rated as "Somewhat increase", as mechanisms include wind, foraging animals, and flowing water (Wolf et al. 2006).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Increase. Species is moderately restricted to relatively cool or cold environments (fen at 9,500 ft).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Greatly Increase. *Drosera rotundifolia* is an obligate wetland species that requires continuously moist or saturated soils and is found in sites with shallow water table depths (Reed 1988).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in fens below Mount Emmons, and likely depends on deep snow cover.

C3) Restriction to uncommon geological features or derivatives. Increase. *Drosera rotundifolia* is an obligate wetland species that requires continuously moist or saturated soils and is found in sites with shallow water table depths (Reed 1988).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. Pollination of *D. rotundifolia* occurs most often through self-pollination of the hermaphroditic flowers (Engelhardt 1998).

C4d) Dependence on other species for propagule dispersal. Neutral. Dispersal mechanisms include wind, foraging animals, and flowing water (Wolf et al. 2006).

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Somewhat Increase. Preliminary studies suggest the Colorado occurrences are extremely similar genetically, but it is still possible that individual occurrences may contain unique alleles, and occurrence extirpation might result in the loss of important genetic diversity (Cohu 2003).

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

<u>Literature Cited</u>

Cohu, C. 2003. Population genetic analysis of Colorado's *Drosera rotundifolia* using allozyme electrophoresis. Thesis. Western State College, Gunnison, CO.

Engelhardt, T.L. 1998. Pollination ecology of the round-leaved sundew, *Drosera rotundifolia* L. (Droseraceae), in Sequoia National Park, California. California State University - Fullerton, Fullerton, CA.

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Reed, P.B. 1988. 1988 Official Wetland Plant List & 1993 Supplement. US Fish and Wildlife Service.

Wolf, E., E. Gage, and D.J. Cooper. 2006. *Drosera rotundifolia* L. (roundleaf sundew): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. http://www.fs.fed.us/r2/projects/scp/assessments/droserarotundifolia.pdf [Accessed July 1, 2011].

19. Low fleabane (*Erigeron humilis*)

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Known occurrences have been documented from 11,000-13,300 feet.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral. Seeds are wind-dispersed, and characterized by moderate dispersal capability.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine above 11,000 ft.

C3) Restriction to uncommon geological features or derivatives. Neutral. No data, forced score.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. Plumed achenes are likely wind-dispersed.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

20. Woolly fleabane (*Erigeron lanatus*)

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Known occurrences have been documented above 11,500 feet.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral. Seeds are wind-dispersed, and characterized by moderate dispersal capability.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or ‘Greatly Increase’, having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked ‘Somewhat Decrease’.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine above 11,500 ft.

C3) Restriction to uncommon geological features or derivatives. Somewhat Increase. Species is found growing on limestone talus (FNA eds. 1993+).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral**.** Plumed achenes are likely wind-dispered.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

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21. Colorado buckwheat (*Eriogonum coloradense*)

Ecological System/Habitat: Alpine, Aspen, Spruce-fir

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Known occurrences range from 9,500-12,800 feet.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral. The seeds of *Eriogonum* species are dispersed by wind, rain, streams, and animals (Stokes 1936).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Increase. Species is restricted to relatively cool or cold environments (alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine between 9,500 and 12,820 feet.

C3) Restriction to uncommon geological features or derivatives. Neutral. *E. coloradense* has been documented on granitic, shale, limestone, and sandstone (Anderson 2004).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Unknown.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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Anderson, D.G. 2004. *Eriogonum coloradense* Small (Colorado buckwheat): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/eriogonumcoloradense.pdf. [Accessed July 6, 2011].

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Stokes, S.G. 1936. The Genus *Eriogonum* - a Preliminary Study Based on Geographic Distribution. J.H. Neblett Pressroom, San Francisco, CA.

22. **Altai cottongrass (*Eriophorum altaicum var. neogaeum*)**
Ecological System/Habitat: Groundwater-dependent wetlands (fens)
B1) Exposure to sea level rise. Neutral.
B2a) Distribution relative to natural barriers. Somewhat Increase. *E. altaicum* var. *neogaeum* has been documented in the Gunnison Basin above 11,500 feet.
B2b) Distribution relative to anthropogenic barriers. Neutral.
B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Somewhat Increase. Dispersal is likely by wind and water, as this is a wetland/fen species.
C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.
C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is moderately restricted to relatively cool or cold environments (fens above 11,500 ft).
C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'..
C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Greatly Increase. *E. altaicum var. neogaeum* is a species found in wet meadows and fens, and requires continuously moist or saturated soils.
C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.
C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in fens at or above treeline, and likely depends on deep snow cover.

C3) Restriction to uncommon geological features or derivatives. Increase *E. altaicum var. neogaeum* is a species found in wet meadows and fens, and requires continuously moist or saturated soils.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. Likely wind-pollinated.

C4d) Dependence on other species for propagule dispersal. Neutral. Seeds are likely dispersed through wind and water.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

23. Black Canyon gilia (*Gilia penstemenoides*)

Ecological System/Habitat: Aspen, Oak and mixed mountain shrubland, and Spruce-fir

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Somewhat Increase. The core population of *G. penstemenoides* is located on cliffs on either side of a large natural barrier, the Black Canyon of the Gunnison. The Black Canyon is bisected by the Gunnison River.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral. Dispersal distances are unknown for *G. penstemenoides,* but likely occurs by wind and rain (Beatty et al. 2004).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral. Species is not significantly affected by thermal characteristics of the environment in the assessment area, or species occupies habitats that are thought to be not vulnerable to projected climate change.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Neutral. The species has experienced **average (21-40 inches/509-1,016 mm)** precipitation variation in the past 50 years. Data from the Cimarron weather station (nearest to *G. penstemenoides* core habitat and occurrences) shows total monthly precipitation ranging from 5.8 to 30.05 inches (Colorado Climate Trends 2011).

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Neutral. *G. penstemenoides* has no documented dependence on a strongly seasonal hydrologic regime (Beatty et al. 2004).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover.
C3) Restriction to uncommon geological features or derivatives. Neutral. Known from igneous outcrops, sedimentary influences, and metamorphic rock types (Beatty et al. 2004).
C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.
C4c) Pollinator Versatility. Neutral. No data, forced score.
C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.
C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.
C5) Genetic factors. Unknown.
C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Beatty, B.L., W.F. Jennings, and R.C. Rawlinson. 2004. *Gilia penstemonoides* M.E. Jones (Black Canyon gilia): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. http://www.fs.fed.us/r2/projects/scp/assessments/giliapenstemonoides.pdf [Accessed July 2, 2011].

Colorado Climate Trends. 2011. Total Annual Precipitation Historic Data from Cochetopa Creek weather station. http://climatetrends.colostate.edu/. Accessed June 6, 2011.

24. Colorado wood-rush (*Luzula subcapitata*)

Ecological System/Habitat: Groundwater-dependent wetlands (fens)
B1) Exposure to sea level rise. Neutral.
B2a) Distribution relative to natural barriers. Somewhat Increase. *L. subcapitata* has been documented in fens of the Gunnison Basin above 10,500 feet (FNA 1993+).
B2b) Distribution relative to anthropogenic barriers. Neutral.
B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Somewhat Increase. Dispersal is likely by wind and water, as this is a wetland/fen species.
C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.
C2aii) Predicted sensitivity to temperature: physiological thermal niche. Increase. Species is moderately restricted to relatively cool or cold environments (fens above 10,500 ft).
C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in

the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Greatly Increase. *L. subcapitata* is a species found in wet meadows and fens, and requires continuously moist or saturated soils.

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in fens in the subalpine or above treeline, and likely depends on deep snow cover.

C3) Restriction to uncommon geological features or derivatives. Increase. *L. subcapitata* is a species found in fens, and requires continuously moist or saturated soils.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. Likely wind-pollinated.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

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25. Colorado tansy-aster (*Machaeranthera coloradoensis*)

Ecological System/Habitat: Montane grassland, Montane sagebrush

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral and Somewhat Increase. Occurrences in the Gunnison Basin are located in montane habitats ranging from 9,000-10,000 feet (Beatty et al. 2004).

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral. Seeds of *M. coloradoensis* contain a bristly pappus that likely acts as a parachute, so it is likely wind dispersed (Beatty et al. 2004).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. *M. coloradoensis* has experienced average temperature variation in the last 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral and Somewhat Increase. Species is somewhat (10-50% of range) restricted to relatively cool or cold environments (upper subalpine) in the Gunnison Basin.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover, as it is known to occupy sparsely vegetated, steep, rocky slopes (Beatty et al. 2004).

C3) Restriction to uncommon geological features or derivatives. Neutral. Known to occur on the following substrates: limestone, dolomite, shale, volcanic ash, and granite (Beatty et al. 2004).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. Bristly pappus on achene aids in wind-dispersal.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

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Beatty, B.L., W.F. Jennings, and R.C. Rawlinson. 2004. *Machaeranthera coloradoensis* (Gray)

Osterhout (Colorado tansyaster): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/machaerantheracoloradoensis.pdf [Accessed July 2, 2011].

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26. Grand Mesa penstemon (*Penstemon mensarum*)

Ecological System/Habitat: Montane sagebrush

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral. Occurrences in the Gunnison Basin are located in largely open, montane habitats ranging from 8,000-10,000 feet (Lyon and Kuhn 2010).

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Neutral. Species is not significantly affected by thermal characteristics of the environment in the assessment area, or species occupies habitats that are thought to be not vulnerable to projected climate change.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Neutral. *P. mensarum* has no documented dependence on a strongly seasonal hydrologic regime.

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. No dependence on ice or snow cover has been documented for *P. mensarum*.

C3) Restriction to uncommon geological features or derivatives. Neutral. Is known to occur on a variety of substrates (Lyon and Kuhn 2010).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Lyon, P. and B. Kuhn. 2010. Grand Mesa National Forest Boreal Toad and Rare Plant Survey. Colorado Natural Heritage Program Report. On File at Colorado Natural Heritage Program, Fort Collins, Colorado.

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27. Avery peak twinpod (*Physaria alpina*)

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Occurs above 12,000 feet in the Gunnison Basin.

B2b) Distribution relative to anthropogenic barriers. Neutral**.**

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (upper subalpine/alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found in the alpine above 12,000 ft.

C3) Restriction to uncommon geological features or derivatives. Neutral. No data, forced score.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Unknown.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

28. Rollins twinpod (*Physaria rollinsii*)

Ecological System/Habitat: Low elevation sagebrush

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Neutral.

B2b) Distribution relative to anthropogenic barriers. Neutral**.**

B3) Impact of land use changes resulting from human responses to climate change. Neutral.

C1) Dispersal and movements. Neutral.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Somewhat Decrease. Species has experienced a greater than average temperature (>70°F/43.0°C) variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat Increase. Species is somewhat restricted to cool or cold environments that may be lost as a result of climate change. Temperatures in the *P. rollinsii* occupied habitat can dip below freezing any month of the year. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer. Because the habitat for *Astragalus anisus* [which is shared by *P. rollinsii*] is already xeric, lower soil moistures in the growing season induced by decreased precipitation could have serious impacts (Decker and Anderson 2004).

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Increase. The species has experienced **small (4-10 inches/100-254 mm)** precipitation variation in the past 50 years. Data from the Cochetopa Creek weather station (adjacent to known *P. rollinsii* occurrences, 8,000 feet) shows total monthly precipitation ranging from 6.8 to 17.78 inches (Colorado Climate Trends 2011).

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Neutral. Species has little dependence on a strongly seasonal hydrologic regime or localized moisture regime that is highly vulnerable to loss or reduction with climate change. Precipitation amounts are fairly evenly distributed throughout the seasons, with somewhat more moisture being received during the "monsoon" season of July and August (Decker and Anderson 2004).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. Little dependence on snow or ice cover.

C3) Restriction to uncommon geological features or derivatives. Neutral. No data, forced score.

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Neutral. No data, forced score.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

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29. **Tundra buttercup (*Ranunculus gelidus*)**

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Occurs above 12,000 feet.

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Neutral. No data, forced score.
C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral.
C2aii) Predicted sensitivity to temperature: physiological thermal niche. Greatly Increase. Species is completely or almost completely restricted to relatively cool or cold environments (alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.
C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.
C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).
C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.
C2d) Dependence on ice, ice-edge, or snow cover habitats. Greatly Increase. Species is found in the alpine above 12,000 ft, and is found in snow-melt areas on the edges of snowfields.
C3) Restriction to uncommon geological features or derivatives. Neutral. Parent material for soils at documented occurrences are reported as igneous, gneiss, schist, and limestone (Spackman et al. 2006).
C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.
C4c) Pollinator Versatility. Unknown. No data, forced score.
C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.
C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.
C5) Genetic factors. Unknown.
C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

National Resource Conservation Service (NRCS). 2011. Historical climate data from Snotel site at Schofield Pass, Colorado. Available online: http://www.wcc.nrcs.usda.gov/nwcc/site?sitenum=737&state=co.

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30. **Hanging garden Sullivantia (*Sullivantia hapemanii var. purpusii*)**

Ecological System/Habitat: Montane riparian

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. *Sullivantia hapemanii* var. *hapemanii* is a riparian species that has narrow ecological amplitude and occupies fragile habitat, specifically coldwater spring, seep, and streamside settings at low- and mid-montane elevations generally associated with limestone outcrops (Heidel 2004).

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Increase. Seeds of *S. hapemanii var. purpusii* are likely water dispersed, but that has not been addressed in the literature (Heidel 2004). Dispersal distance is dependent on slope and proximity to water.

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. Species has experienced average temperature variation in the last 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Somewhat Increase to Increase. Species is somewhat (10-50% of range) to largely (50-90%) restricted to relatively cool or cold environments (upper subalpine) in the Gunnison Basin.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'. Elevations of known occurrences in the Gunnison Basin range from 9,000-10,000 feet.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Greatly Increase. *Sullivantia hapemanii* var. *hapemanii* is a riparian species that has narrow ecological amplitude and occupies fragile habitat, specifically coldwater spring, seep, and streamside settings at low- and mid-montane elevations (Heidel 2004).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Neutral. No dependence on ice or snow cover has been documented.

C3) Restriction to uncommon geological features or derivatives. Increase. Species is generally associated with limestone outcrops (Heidel 2004).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. Species frequently sets fruit by self-fertilization (Heidel 2004).

C4d) Dependence on other species for propagule dispersal. Neutral. No data, forced score.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

Heidel , B. 2004. *Sullivantia hapemanii* var. *hapemanii* (Coult. & Fisher) Coult. (Hapeman's coolwort): a technical conservation assessment. [Online]. USDA Forest Service, Rocky Mountain Region. Available: http://www.fs.fed.us/r2/projects/scp/assessments/sullivantiahapemaniivarhapemanii.pdf. [Accessed June 1, 2011].

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31. Rothrock townsend-daisy (*Townsendia rothrockii*)

Ecological System/Habitat: Alpine

B1) Exposure to sea level rise. Neutral.

B2a) Distribution relative to natural barriers. Increase. Known occurrences range from 8,000-13,500 feet, although the majority are located above 10,000 feet (Beatty et al. 2004).

B2b) Distribution relative to anthropogenic barriers. Neutral.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Somewhat Increase. Details of seed dispersal mechanisms in *Townsendia rothrockii* have not been studied. *Townsendia rothrockii* flowers and seeds are close to the ground where wind (common at high elevations), water movement (e.g., sheets of rain, snow melt off), soil movement (e.g., erosion), and animal vectors (e.g., small mammals, ants) could possibly disperse the seeds. This species has bristles on the achenes that could facilitate dispersal (Zomlefer 1994). Presumably, dispersal success of *T. rothrockii* may depend on wind and precipitation patterns, substrate characteristics, animal activities, topographic heterogeneity, and availability of suitable "safe" sites (Beatty et al. 2004).

C2ai) Predicted sensitivity to temperature: historic thermal niche. Neutral. This species has experienced slightly lower than average (47.1-57°F/26.3-31.8°C) temperature variation in the past 50 years.

C2aii) Predicted sensitivity to temperature: physiological thermal niche. Increase. Species is restricted to relatively cool or cold environments (alpine). Alpine habitats are likely to be reduced as Colorado becomes warmer, and presumably drier. Climate models project earlier, faster snowmelt along with decreased summer precipitation and increased summer temperatures (Barsugli 2010). This would result in significantly lower amounts of water stored in the soils during the summer.

C2bi) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: historical hydrological niche. Somewhat Decrease. Initially, ratings for this factor were calculated in GIS by overlaying the species' distributions on mean annual precipitation data (PRISM 4km annual average precipitation, in inches, 1951-2006) downloaded from ClimateWizard, and subtracting the lowest pixel value from the highest value. Using this method, alpine species were rated as 'Increase' or 'Greatly Increase', having a very low precipitation variation. However, precipitation variation in the alpine in the last 50 years has been high. In order to reflect this variation, we used data from a Snotel site at Schofield Pass (10,070 feet). Historical Accumulated Precipitation data from the site ranges from 34.6 to 69.8 inches for water years 1986-2011 (NRCS 2011). Although the station is below treeline, and not in true alpine, it is the highest elevation Snotel site in the Gunnison Basin. Thus, this alpine species has experienced **greater than average (> 40 inches/1,016 mm)** precipitation variation in the past 50 years, and is ranked 'Somewhat Decrease'.

C2bii) Predicted sensitivity to changes in precipitation, hydrology, or moisture regime: physiological hydrological niche. Somewhat Decrease. Species likely has a broad moisture regime tolerance (see C2bi).

C2c) Dependence on a specific disturbance regime likely to be impacted by climate change. Neutral. No data, forced score.

C2d) Dependence on ice, ice-edge, or snow cover habitats. Increase. Species is found between 8,000 and 13,500 feet (Beatty et al. 2004).

C3) Restriction to uncommon geological features or derivatives. Neutral. *T. rothrockii* has since been found on a variety of substrates, such as rocky soils, steep talus, dry rocky soil, granite talus, lava cliffs, limestone outcrops, red sandstone, thin red soil, loam soil, and limey substrates (Beatty et al. 2004).

C4a) Dependence on other species to generate habitat. Neutral. No data, forced score.

C4c) Pollinator Versatility. Neutral. No data, forced score.

C4d) Dependence on other species for propagule dispersal. Unknown.

C4e) Forms part of an interspecific interaction not covered by C4a-d. Unknown.

C5) Genetic factors. Unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

Literature Cited

Barsugli, J. 2010. Hydrologic Projections for the Gunnison Basin. Presentation at Follow-up meeting for the Climate Change Adaptation Workshop. Gunnison, Colorado.

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APPENDIX H: Animal Species Summaries: CCVI Documentation

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Animal summaries are listed by taxon group in the following order.

Number	Group/Latin Name	Common Name
1.	***Amphibians***	
	Anaxyrus boreas	Boreal toad
	Lithobates pipiens	Northern Leopard Frog
2.	***Birds***	
	Accipiter gentilis	Northern Goshawk
	Aegolius funereus	Boreal Owl
	Amphispiza belli	Sage Sparrow
	Centrocercus minimus	Gunnison Sage-grouse
	Cypseloides niger	Black Swift
	Lagopus leucura	White-tailed Ptarmigan
	Leucosticte australis	Brown-capped Rosy-Finch
	Melanerpes lewis	Lewis's Woodpecker
3.	***Fish***	
	Oncorhynchus clarkii	Cutthroat Trout
4.	***Mammals***	
	Cynomys gunnisoni	Gunnison's Prairie Dog
	Gulo gulo	Wolverine
	Lepus americanus	Snowshoe Hare
	Lynx lynx	Lynx
	Ochotona princeps	American pika
	Ovis canadensis	bighorn sheep
	Corynorhinus townsendii pallescens	Townsend's big-eared bat
	Sorex hoyi montanus	Pygmy Shrew
	Sorex nanus	dwarf shrew
5.	***Insects***	
	Boloria improba acrocnema	Uncompahgre Fritillary

1. AMPHIBIANS

Boreal Toad (*Anaxyrus boreas boreas*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers. Known breeding is restricted to an elevation range of 8,000 – 12,000 feet (Hammerson 1999; Lambert 2011). Montane habitat required with permanent pools in summer to breed and wet areas for dispersal.

B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area. Problems for this species would include damming rivers or streams, which is not likely in the study area where this species is found.

C1) Dispersal and movements. Dispersal distances are not well known, but movement distances of up to 4 km between breeding and non-breeding habitats have been observed (S. Corn, unpublished data cited in Hammerson 1999). Additionally, Lambert (2011) has documented movements of greater than 9 km.

C2) Sensitivity to temperature and moisture changes. For breeding, this species generally tends to pick warmer spots; breeding ponds tend to range from cold to bathwater warm. Water temperatures where tadpoles have been found are typically in the low 60s to 70s (degrees F), with the warmest near 78° F (B. Lambert, pers. comm.). However, if ponds in future range from warm to hot, toads may start picking cooler spots. Toads are highly dependent on specific hydrology for breeding. More snow provides more insulation for warmer hibernation which leads to better winter survival.

C3) Restriction to uncommon geological features or derivatives. Not tied to any specific geologic feature.

C4) Reliance on interspecific interactions. Dependence on other species – beaver. Almost all current known breeding sites are beaver pond complexes. Assume beavers are moderately vulnerable to climate change (expect warmer and drier) but at montane elevations maybe not enough to cause population declines.

C5) Genetic factors. Most breeding populations within the Southern Rocky Mountain Group examined by Switzer et al. (2009) are isolated from one another with limited gene flow among populations.

<u>Literature Cited</u>

Hammerson, G. A. 1999. Amphibians and Reptiles in Colorado. Second edition. University Press of Colorado and Colorado Division of Wildlife, Niwot, CO. 484 pp.

Lambert, B. 2011. Colorado Natural Heritage Program boreal toad survey and monitoring project 2010. Report prepared for the Colorado Division of Wildlife.

Switzer, J. F., R. Johnson, B. A. Lubinski, and T. L. King. 2009. Genetic structure in the *Anaxyrus boreas* species group (Anura, Bufonidae): an evaluation of the Southern Rocky Mountain population. A final report submitted to the U.S. Fish and Wildlife Service, Mountain-Prairie Region, 4 December 2009.

Northern Leopard Frog (*Lithobates pipiens*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers.

a. **Natural**. Neutral. This species is distributed from subalpine to semi-desert habitats (Hammerson 1999). While habitat patchiness occurs, there are no natural barriers to their dispersal to other landscapes.
b. **Anthropogenic**. Neutral. However, we note that the reservoir presents a local barrier to dispersal. Individuals and populations remain connected by circumventing the reservoir.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. Land use is not expected to change locally in response to climate change.

C1) Dispersal and movements. Somewhat decrease. Movements up to 4.0 km overland (adults) and 5.2 km (subadults) in Alberta and Michigan respectively (Seburn et al. 1997; Dole 1971).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
   i. **Historical Thermal Niche**. Neutral. (NatureServe Climate Change Vulnerability Index factor C2ai (2010). – see map provided by NatureServe.
   ii. **Physiological Thermal Niche**. Neutral**.** This species occurs in widely diverse habitat and elevations (Hammerson 1999).
b. **Hydrology**
   i. **Historical Hydrological Niche.** Somewhat Increase to Increase. Climate is always highly variable in the Gunnison Basin. Predictions are that drought events may be more severe than what has occurred in the last 50 years; therefore, variability has been relatively low. (Ray et al. 2008; Grand Mesa, Uncompahgre and Gunnison National Forests 2011).
   ii. **Physiological hydrological niche**. Somewhat Increase. This frog lives in diverse habitats (Hammerson 1999). Increased drought (and/or moisture deficit) could cause losses or reductions in habitat and potential increase mortality from egg to adult. Water quality could degrade with increasing fire frequency (Smith and Keinath 2007; NatureServe 2010).
c. **Dependence on a specific disturbance regime.** Somewhat Increase. Chytrid fungus can greatly influence populations. More fire is likely to degrade water quality in affected watershed.
d. **Dependence on snow-covered habitats.** Neutral

C3) Restriction to uncommon geological features or derivatives. Somewhat Decrease. This species is very flexible in its habitat requirements.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Somewhat Increase. Beaver greatly increase habitat quality and quantity in stream courses (Hammerson 1999; Smith and Keinath 2007; NatureServe 2010) and can buffer some climate-induced changes in hydrology.
b. **Dietary versatility.** Neutral. Highly diverse diet (Hammerson 1999; Smith and Keinath 2007).

C5) Genetic factors.

a. **Measured genetic variation.** Somewhat Increase. Genetic diversity was found to be lower compared to eastern populations (Hoffman and Blouin 2004).
b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Neutral. Although it is likely that initial annual calling dates are happening earlier, the impacts are not known.

D1) Response to recent climate change. Somewhat Increase to Increase. Brodkin et al. (1992) suggest that the correlation of declines and climate change are likely related when they found that disease frequency increased at higher laboratory temperatures.
D2) Modeled future change in population or range size. Unknown
D3) Overlap of modeled future range with current range. Unknown
D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new nest sites is likely.

Literature Cited

Brodkin, M. A., et al. 1992. Response of *Rana pipiens* to graded doses of the bacterium *Pseudomonas aeruginosa.* J Herpetology 26(4):490-495.

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2. BIRDS

Northern Goshawk (*Accipiter gentilis*)
B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers.

a. **Natural.** Neutral. The species is highly volant and therefore there are no significant barriers, natural or anthropogenic for this species. Goshawks are known to have long distance migration when conditions are not good (Squires and Reynolds 1997; Kennedy 2003)
b. **Anthropogenic.** Neutral. Same reasoning as in B2.a.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. Assumption that land use will not change in most of the species' habitat as a result of climate change. The forests of the area are largely being managed for some kind of conservation (TNC Measures Report).

C1) Dispersal and movements. Decrease. Goshawks have relatively large home ranges, requiring significant dispersal (Squires and Reynolds 1997). In addition, Goshawks exhibit long distance migration (as a species) and irruptive movement (Kennedy 2003; USFWS 1998).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
   i. **Historical Thermal Niche**. Quite variable locally (see ClimateWizard). However, the species ranges from the boreal forests to western Mexico, indicating that the thermal niche is variable (see global range map in Kennedy 2003). Also, see genetics section which notes that the species has significant gene flow.
   ii. **Physiological thermal niche.** Neutral. Goshawks do not apparently specialize in cold environments; but choose forests, particularly those stands that are mature. Nearly all forests in the study area are used as happens in other parts of the range with a preference for older forests (Kennedy 2003; Daw et al. 1998)

b. **Hydrology**
   i. **Historical Hydrological Niche.** Somewhat Increase to Increase. Precipitation history in most of the range is variable. See ClimateWizard. Precipitation during the breeding season is assumed to be less variable (at the initiation?)
   ii. **Physiological Hydrological Niche.** Neutral to Somewhat Decrease. Goshawks nest in arid SW forest and moist montane to subalpine forests as well as in the temperate rainforests of the Pacific NW (Squires and Reynolds 1997; Kennedy 2003). Local populations could be impacted by increases in spring storms (Hoglund 1964). However, adult survival is the strongest variable in population trend (Kennedy 2003).

C3) Restriction to uncommon geological features or derivatives. Neutral. Not restricted to such factors.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Neutral. Goshawks do not depend on other species to generate nesting habitat.
b. **Dietary versatility.** Neutral to Somewhat Increase. Goshawks consume a wide variety of prey (Squires and Reynolds 1997). However, red squirrels, grouse, and hares make up the largest portion of the diet (summarized in Kennedy 2003). These prey species vary in numbers temporally and spatially, a factor that could interact with climatically derived changes in severe weather/climate including changes in fire regimes (e.g., spring storms, droughts, etc.) (Boal et al. 2002).

C5) Genetic factors.

a. **Measured genetic variation.** Increase. In North America it appears that there is extensive gene flow among populations (Gavin and May 1996). Genetic diversity values are relatively low for N. American goshawks but may be normal for the species. However, the low diversity is raised as a cautionary issue in this vulnerability assessment.
b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown. Not applicable.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Neutral. No known response to climate shifts. But mean egg-laying date shifted with altitude in Britain (Marquiss and Newton 1982), indicating the potential to respond to variation in the weather/climate.

D1) Response to recent climate change. Neutral. No known responses.

D2) Modeled future change in population or range size. Neutral to Increase. No modeled population changes; however, models of forest type changes suggest overall habitat declines in size, distribution, and quality – see habitat assessment in this workshop.

D3) Overlap of modeled future range with current range. Same justification as in D2.

D4) Protected areas. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new nest sites is likely.

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U. S. Fish and Wildlife Service. 1998. Status review of the northern goshawk in the forested west. Unpublished Report. Office of Technical Support, Forest Resources, Portland Oregon.

Boreal Owl (*Aegolius funereus*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers.

a. **Natural**. Neutral. This species makes long distance movements; The ineffectiveness of any perceived barriers is demonstrated by near genetic continuity in North American population (Koopman et al. 2007)
b. **Anthropogenic.** Neutral. Boreal owls are highly Volant (NatureServe 2010); reference statement above in B2) A.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. No large scale land use changes are expected in this area (see USFS and BLM plans as well as local land use plans).

C1) Dispersal and movements. Decrease. Modest movements are typical. But long distance dispersal is regular (Hayward and Hayward 1993).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
    i. **Historical Thermal Niche.** Neutral. (NatureServe Climate Change Vulnerability Index factor C2ai (2010). – see map provided by NatureServe.
    ii. **Physiological Thermal Niche.** Greatly Increase. Lives exclusively in high elevation forests of Gunnison study area and in the Rocky Mountain region (Hayward and Hayward 1993; NatureServe 2010)
b. **Hydrology**
    i. **Historical Hydrological Niche.** Neutral. Snow is expected to continue in subalpine forests. No discernable trends are currently expected (CWCB 2008)
    ii. **Physiological hydrological niche.** Increase. Increase snowmelt rate; decline in summer soil moisture; increases in severe storm frequency (Hayward and Hayward 1993; TNC Climate Scenarios (2010); Grand Mesa, Uncompahgre and Gunnison National Forests (2010)
c. **Dependence on a specific disturbance regime.** Somewhat Increase. Climate change will change fire regime for all forests, increasing at least the frequency of fire (Hayward and Hayward 1993).
d. **Dependence on snow-covered habitats.** Increase. Although it is not entirely clear what the impact could be, there will be earlier snow-melt and more periods with low snow cover. However, some scenarios suggest increases in snow during winters, known to reduce hunting success.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Neutral.
b. **Dietary versatility.** Neutral to Somewhat Increase. Depends on small mammals and small birds. Small mammal numbers may be influenced by changes in climate, especially precipitation and

soil moisture (Hayward and Hayward 1993; Hayward USFS R2 Sensitive Species Assessments (n.d.)).

C5) Genetic factors.

a. **Measured genetic variation.** Neutral. Genetic variability average; continuity across range in North America demonstrates connectivity or continuity of populations (Koopman et al. 2007).
b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Neutral. Flexible response to climate variables demonstrated by shifts in nesting time, triggers for emigration/eruptions, etc.

D1) Response to recent climate change. Neutral. None documented for this species.

D2) Modeled future change in population or range size. Unknown. No models for this species located, but ecological models for forest types used by this species show changes in composition/structure and declines in area covered (see Climate Workshop information)

D3) Overlap of modeled future range with current range. Unknown.

D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new nest sites is likely.

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Sage Sparrow (*Amphispiza belli*)

B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers. Volant - no barriers
B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Long-distance dispersal ability.
C2) Sensitivity to temperature and moisture changes. Neutral
C3) Restriction to uncommon geological features or derivatives. Not tied to any specific geologic feature.
C4) Reliance on interspecific interactions. Ground-feeding omnivore during the breeding season (Martin and Carlson 1998).
C5) Genetic factors. Unknown

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Gunnison Sage-grouse (*Centrocercus minimus*)
B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers.

a. **Natural.** Neutral to Somewhat Increase. There would appear to be habitat barriers for the sage-grouse; however, it is mitigated by their ability to disperse long distances.
b. **Anthropogenic.** Neutral. Anthropogenic barriers to the sage-grouse are relatively small and include urban areas and highways (Gunnison Sage-grouse Rangewide Steering Committee 2005). Based on radio telemetry data, there are no anthropogenic barriers within the Gunnison Basin that are considered barriers to movement (M. Phillips, pers. comm.).

B3) Impact of land use changes resulting from human responses to climate change. Somewhat Increase. Most of the sage-grouse habitat is public lands or ranchlands (Gunnison Sage-grouse Rangewide Steering Committee 2005). Under certain climate conditions there may be more pressure to graze intensely. Geothermal development has the potential to impact 15% - 20% of this species' habitat within the Gunnison Basin.
C1) Dispersal and movements. Somewhat Decrease. Gunnison's Sage-grouse generally move less than 10 km; however, they are known to disperse more than 35 km (Gunnison Sage-grouse Rangewide Steering Committee 2005).
C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
    i. **Historical Thermal Niche.** Somewhat Decrease. See map provided by NatureServe. NOTE: Gunnison Valley is among the coldest areas in Colorado. This local climate may not be accurately portrayed by general maps.
    ii. **Physiological Thermal Niche.** Neutral. Gunnison's Sage-grouse does not specifically select colder parts of their habitat.
b. **Hydrology**
    i. **Historical Hydrological Niche.** Neutral. Range of variation in precipitation is moderate.
    ii. **Physiological Hydrological Niche.** Greatly Increase. Brood-rearing habitat is thought to be the most limiting part of the life history. High quality brood-rearing habitat

includes mesic meadows, springs, seeps, and low vegetation riparian areas, all dependent on adequate moisture (Gunnison Sage-grouse Rangewide Steering Committee 2005). This habitat has already been seriously degraded over the past century or more with some good restoration initiated in the past decade or so.

c. **Dependence on a specific disturbance regime.** Increase. Fire is a natural occurring event in sage-brush, apparently creating a patchwork of lower and higher density sage. Changes in this fire regime could have deleterious impacts on the sage-grouse (Rhodes et al. 2010; Gunnison Sage-grouse Rangewide Steering Committee 2005)
d. **Dependence on snow-covered habitats.** Somewhat Increase**.** Not dependent on snow-covered habitats.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Neutral. No known species create important habitats for Gunnison's Sage-grouse.
b. **Dietary versatility.** Increase. Gunnison's Sage-grouse feeds on a large number of grasses, forbs, buds, and insects when available (Gunnison Sage-grouse Rangewide Steering Committee 2005), but they are heavily reliant upon sage. They also depend on herbs and forbs in the summer along with the insects that use the same habitat (important for chick growth); factors that could be impacted by climate change to the degree that it includes droughts and hot spells.

C5) Genetic factors.

a. **Measured genetic variation.** Somewhat Increase to Increase. Measured genetic variability is low for the species (Oyler-McCance 2005). However, the Gunnison population has the highest variability.
b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown.

D1) Response to recent climate change. Neutral (or Unknown).

D2) Modeled future change in population or range size. Neutral. Models to predict range or population sizes of the Gunnison's Sage-grouse have not be reported except via a population viability analysis used in the development of the rangewide conservation plan (Gunnison Sage-grouse Rangewide Steering Committee 2005). In addition, there are some models of how sage-brush might respond to climate change. It appears that the fate of sage-brush in the region depends on precipitation patterns and subsequent fire frequency (Gunnison Sage-grouse Rangewide Steering Committee 2005).

D3) Overlap of modeled future range with current range. Unknown.

D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new inhabited areas is likely.

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Black Swift (*Cypseloides niger*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers. Volant - no barriers

B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Long-distance dispersal ability.

C2) Sensitivity to temperature and moisture changes. This species' close association with waterfalls for nest sites (Lowther and Collins 2002) greatly increases its vulnerability; this association within the Gunnison Basin affects its score in both the hydrologic and geologic sections. The degree to which streams on which these waterfalls are found will be affected by climate change is uncertain; Knorr (1961) first suggested that this species will not nest on intermittent streams and that even in drought years where the stream was reduced to a trickle, birds returned to their nesting sites (Knorr 1961; Knorr 1993). The degree to which perennial streams that feed waterfalls with nesting sites become intermittent due to climate change seems to be the primary factor in determining how vulnerable nesting sites may be. Levad et al. (2008) did find that increased stream flow contributed to a higher probability that a waterfall would be occupied.

C3) Restriction to uncommon geological features or derivatives. This species' close association with waterfalls for nest sites (Lowther and Collins 2002) greatly increases its vulnerability.

C4) Reliance on interspecific interactions. Diet items are diverse, but primarily limited to flying insects (Lowther and Collins 2002).

C5) Genetic factors. Unknown.

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Peregrine Falcon (*Falco peregrinus*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers. Volant - no relevant natural or anthropogenic barriers for this species in the Gunnison area. Very strong flyer, moving long distances in migration (for those populations that migrate). Two individuals from southern Utah migrated through western Mexico, one continuing to a wintering site in Nicaragua (Britten et al. 1995)

B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area. Except when disturbed at the nest site or hunted, peregrines are tolerant of humans (White et al. 2002). Nest sites are placed so that they are generally difficult to access by humans and most other potential predators.

C1) Dispersal and movements. Long-distance dispersal ability (Britten et al. 1995; NatureServe 2010; White et al. 2002). Even the foraging distance can be > 27 km² (Martin 1979; Porter and White 1973).

C2) Sensitivity to temperature and moisture changes. Strong ability to behaviorally maintain core body temperature even when ambient temps vary from 20-50^0 C (Mosher and White 1978; Bartholomew and Cade 1957). Not dependent on wetlands and shorelines in Colorado; therefore, hydrological considerations are not strongly relevant. Peregrines in the Hudson Bay area are being exposed to more storms during the breeding season, increasing mortality in some years (Bradley et al. n.d.). Although climatic disturbances may result in unpredictable storm increases, it is not believed that it will impact Peregrine Falcons in Colorado (assumption).

C3) Restriction to uncommon geological features or derivatives. This species' close association with cliffs and rock outcrops for nesting is well known (White et al. 2002). Climate change is unlikely to have an impact on nest site availability or function.

C4) Reliance on interspecific interactions. Diet is highly diverse, includes a large diversity of birds along with a few mammals (Sherrod 1978; White et al. 2002).

C5) Genetic factors. Genetic variation of N. American populations might be lower than those of northern Europe (Nesje et al. 2000). However, the concerns of Nesje et al. (2000) could have been from low sample sizes of North American specimens. Johnson et al. (2010) demonstrated no distinction in measures of genetic diversity over time in North American birds collected at Padre Island, Texas during migration. Most of these birds were from the northern part of their range. Actual genetic diversity of Colorado birds is unknown.

C6) Phenological response. None documented in Colorado.

D1) Response to climate change. No documentation for Colorado populations. Populations in northern regions are showing increased mortality due to increase in severe spring/late winter storms (Bradley et al. n.d.).

D4) Protected areas. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new nest sites is likely.

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Bald Eagle (*Haliaeeatus leucocephalus*)
B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers

a. **Natural.** Neutral to Somewhat Increase. Location of reservoir and fishing areas may temporarily restrict the local distribution (and potentially prime roost sites). However, the species has strong dispersal capabilities and uses them for foraging and roosting (Buehler 2000). Distance from nests to hunting areas are > 10 km in many western areas (Buehler 2000) and even as much as 29 km in Utah (Swisher 1964)

b. **Anthropogenic.** Neutral. Roosts can be removed from feeding locations (see above). This is a highly volant and vagile (mobile) species. Human development in the area can only be in a small portion of the habitat due to the abundance of public lands.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. Land use changes are likely to be small relative to potential habitat (see Theobald 2000).

C1) Dispersal and movements. Decrease. Bald Eagles regularly move more than 10 km from roosts (Buehler 2000 and references within). Also, the species is migratory, often moving more than 1,000 km between breeding and wintering areas (Palmer 1988; NatureServe 2010).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
    i. **Historical Thermal Niche.** Neutral. (NatureServe Climate Change Vulnerability Index factor C2ai (2010). – see map provided by NatureServe. NOTE: temperature extremes in Gunnison Valley may make these broad summaries less useful. But Bald Eagles are exposed to widely ranging temperatures throughout their range (i.e., the entire species).
    ii. **Physiological Thermal Niche.** Neutral. Bald Eagles breed from Florida to Alaska (Buehler 2000; NatureServe 2010) and winter from coastal Alaska to northern Mexico and Florida.

b. **Hydrology**
    i. **Historical Hydrological Niche.** Neutral. Precipitation is variable in western Colorado with occasional severe droughts (such as in 2002) and very wet winters.
    ii. **Physiological hydrological niche.** Neutral. Bald Eagles generally favor areas near water (Buehler 2000; NatureServe 2010). However, they are not restricted to these areas (Buehler 2000) and winter feed on road kills in sagebrush (Buehler 2000) or prairie dogs (personal observation).

c. **Dependence on a specific disturbance regime.** Somewhat Increase. Peak flows and lowest flows may are changing in volume and timing (Ray et al. 2008), potentially impacting the timing and or location of fish movements in the valley's reservoir.

d. **Dependence on snow-covered habitats.** Neutral. Independent of snow-covered habitats.

C3) Restriction to uncommon geological features or derivatives. Neutral. Distribution and habitat not strongly related to uncommon geological features.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Neutral to Somewhat Increase. Bald Eagle distribution has shifted over the past 50-75 years with the development of reservoirs, stocking of fish, and increase in roads and traffic, therefore road-kills. So partly dependent on human land wildlife resource management.

b. **Dietary versatility.** Neutral to Somewhat Increase. Bald Eagles generally prefer fish (NatureServe 2010) but will eat many other species of birds and mammals plus carcasses of livestock and wildlife.

C5) Genetic factors.

a. **Measured genetic variation.** Neutral. Bald Eagles exhibited high variation across their western range (Morizot et al. 1985). The authors found fixed loci in several genes in the very small Arizona population (~12 pairs). However, the other 2 loci were maximally variable. Genetic diversity of 3 congeners placed Bald Eagles as intermediate in diversity measures (Johnson, et al. 2009). The authors concluded that low levels of diversity may be fairly common in these species and it occurred in the Madagascar fish-eagle for many thousands of years.

b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown. Note that bottlenecks may have occurred during very low population sizes during the 1960's, but see Johnson et al. (2009).

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Neutral. None reported.

D1) Response to recent climate change. Neutral. None reported.

D2) Modeled future change in population or range size. Unknown.

D3) Overlap of modeled future range with current range. Unknown.

D4) Protected areas – Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and future habitat is likely.

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White-tailed Ptarmigan (*Lagopus leucura*)

B1) Exposure to sea level rise. Neutral.

B2) Distribution relative to barriers.

a. **Natural.** Somewhat Increase. Ptarmigans are not completely limited by any natural barriers in the study area. However, the alpine communities that are inhabited by ptarmigans are "habitat islands" in a sea of forested mountains.

b. **Anthropogenic.** Neutral. Ptarmigans and most severe human activities are nearly disjunct. Where anthropogenic activities spatially overlap with ptarmigan habitat, it may constitute a disturbance, but in no way could be classified as a barrier. A few roads penetrate the alpine ecosystems of the study area.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. There are no major changes in land use of the alpine environments due to climate change response.

C1) Dispersal and movements. Somewhat Decrease to Decrease. Most movements of ptarmigan are local but still measured in kilometers (Hoffman 2006). Movement between wintering and breeding areas averages more than 7 km (Braun et al. 1993). However, larger movements/dispersal occurs and can be between 43 and 50 km (Braun et al. 1993). It is notable that measured movement of individuals is not corroborated by genetic data which shows that subpopulations blend, acting as a meta-population or a full, connected population (Fedy et al. 2008).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
    i. **Historical Thermal Niche.** Neutral. Average annual temperatures in the alpine habitat of the Gunnison area vary considerably, exposing the birds to wide variation. However, the number of very high temperatures for extended periods is expected to increase. However, note that the guidance for this assessment calls for the use of NatureServe Climate Change Vulnerability Index factor C2ai (2010) maps.
    ii. **Physiological Thermal Niche.** Greatly Increase. White-tailed ptarmigans spend their entire lives in the cool habitats of the alpine zone (Braun, Martin, and Robb 1993). They are susceptible to heat stress when exposed to high temperatures with no shelter (Hoffman 2006).

b. **Hydrology**
    i. **Historical Hydrological Niche.** Neutral. Precipitation in the Gunnison study area, particularly in the alpine, varies considerably. Some years are nearly without snow and others, like this year in some areas, has more than 500" of snow in a single winter.
    ii. **Physiological hydrological niche.** Increase. Ptarmigans depend on snow cover during the winter for protection from the elements and from predators (Hoffman 2006; Braun, Martin, and Robb 1993; NatureServe 2010). This species is susceptible to heat stress. More importantly, they molt from camouflaged brown plumage into a white winter plumage. When there is little to no snow, the white feathers expose the bird to predators.

c. **Dependence on a specific disturbance regime.** Neutral. Not dependent on specific disturbance regimes (other than precipitation events).

d. **Dependence on snow-covered habitats.** Greatly Increase. Highly dependent on annual snowfall for color-matching during winter periods and for metabolic maintenance (Hoffman 2006).

C3) Restriction to uncommon geological features or derivatives. Neutral. Known to occur almost entirely within the alpine zone of the study area.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Neutral. Does not depend on other species to create or maintain habitat.

b. **Dietary versatility.** Somewhat Increase. White-tailed Ptarmigans have a diverse diet, especially in the summer (May and Braun 1972). The winter diet is much more restrictive (Hoffman 2006). While the species feeds on many species of forbs, grasses and shrubs (buds) and even insects, in winter they depend on willows as the primary food (Hoffman 2006).

C5) Genetic factors.

a. **Measured genetic variation.** Neutral (to Somewhat Increase). Oyler-McCance et al. (2010) showed that over 80 years, the Mt. Evans population of White-tailed Ptarmigan had small declines in heterozygosity.
b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Somewhat Increase. Ptarmigan are known to change colors when there isn't adequate snow for camouflage. Rocky Mountain National Park ptarmigan have initiated egg-laying approximately 2 weeks earlier than historically (Wang et al. 2002).

D1) Response to recent climate change. Neutral. There are no changes in range or distribution documented. However, it is notable that there are estimates of expansion of subalpine vegetation up into the alpine. Also, the distribution in New Mexico has declined, purportedly due to habitat degradation (Ligon 1961)

D2) Modeled future change in population or range size. Somewhat Increase. There are no documented models of future change in population or range size. But there are several habitat models that have estimated composition and areal coverage for major ecosystems, including the alpine.

D3) Overlap of modeled future range with current range. Somewhat Increase. Not done but, as noted before, the vegetation models have been completed for forest types relative to alpine areas, showing overall decline or loss of alpine.

D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new occupied habitat is likely.

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Brown-capped Rosy-Finch (*Leucosticte australis*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers. Volant - no barriers.

B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Long-distance dispersal ability.

C2) Sensitivity to temperature and moisture changes. Nests are found above 11,000 ft., with most above 12,000 feet; Johnson et al. (2000) suggest that temperature may determine lower breeding elevation (Grinnell 1917). Glaciers and/or snowfields may be required for nesting (Johnson et al. 2000); also feeds near lower margins of snowbanks (Johnson et al. 2000).

C3) Restriction to uncommon geological features or derivatives. Cliffs, rockslides, and other irregularities are preferably used for nesting when compared to areas of open tundra (Johnson et al. 2000).

C4) Reliance on interspecific interactions. Omnivorous in both summer and winter (Johnson et al. 2000).

C5) Genetic factors. Unknown.

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Lewis's Woodpecker (*Melanerpes lewis*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers. Volant - no barriers

B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Long-distance dispersal ability.

C2) Sensitivity to temperature and moisture changes. In burned forests, this species is found in areas with high burn severity (Russell et al. 2007) and increased crown fires may be needed to maintain PIPO and nesting habitat for LEWO (Saab and Vierling 2001).

C3) Restriction to uncommon geological features or derivatives. Not tied to any specific geologic feature.

C4) Reliance on interspecific interactions. Classified as a weak excavator, this species uses existing cavities excavated by other species (Tobalske 1997). Feeds on a variety of insects, nuts, and fruit (Tobalske 1997; Abele et al. 2004).

C5) Genetic factors.

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3. FISH

Cutthroat Trout (*Oncorhynchus clarkii*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers.

a. **Natural.** Increase to Greatly Increase. Geological and geomorphological limits to expansion or out of basin movement; in this basin, limited to headwater systems (Young 2008).
b. **Anthropogenic.** Increase to Greatly Increase. Young (2008) and references within described the factors that are barriers or extreme filters to (usually) downstream and/or interbasin dispersal: transportation crossing, stream desiccation, diversion structures, thermal or chemical conditions, and biotic barriers consisting of non-native fish. The most prominent barriers in the Gunnison areas are reservoirs and unsuitable habitat with non-native fish species (Young 2008).

B3) Impact of land use changes resulting from human responses to climate change. Neutral. However, manipulation of existing stream flows to supplement that that could be altered is possible, including diversion for agriculture and snow-making. At this time I think we should consider nearly all options open if serious stress develops.

C1) Dispersal and movements. Somewhat Decrease to Decrease. Movement capability can be up to 50 km for the species in some locations – historically was probably even more (see discussion in Young 2008; NatureServe 2010). Little Snake River movement up to 7.5 km (M. Young, unpublished data as noted in Young 2008).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
   i. **Historical Thermal Niche.** Neutral. (NatureServe Climate Change Vulnerability Index factor C2ai (2010). – see map provided by NatureServe. NOTE: This may not represent stream temperatures for this species in cordilleran habitats. Over the millennia the habitat temperatures have changed with ice age and inter-ice age events over tens of thousands of years. But fish were more likely to move within and perhaps between drainages during those times. More recently, variation has occurred decade long events (or longer) such as

the Hypsithermal period and the Dust Bowl droughts. Records of long, hot periods with even more significant drought are known from tree ring studies.

ii. **Physiological Thermal Niche.** Somewhat Decrease. Cutthroat trout are highly sensitive to rapid water temperature changes (Bear, et al. 2005; Meeuwig, et al. 2004). However, average summer temperature has a strong effect on winter mortality, e.g., warmer summer temperatures increase the growth rate (and if continuing into the fall the length of growing period) of fry, the most sensitive life stage for cutthroat (Harig and Fausch 2002; Coleman and Fausch 2007). Spawning occurs during or after snowmelt peaks and water temperature is a trigger (Quinlan 1980; DeRito 2004). This species is not near its thermal limit within the Gunnison Basin.

b. **Hydrology**

i. **Historical Hydrological Niche**. Increase. Considerable variation occurs naturally with precipitation, melt off and storm flooding in the streams (Ray et al. 2008). Predictions for increasing or decreasing precipitation are circumspect at best; however, predictions for increasing and dynamics in climate variables are compelling. Some researchers suggest that we could see severe droughts that haven't been experienced in historical times (citation?). Elevational complexity is a key factor that challenges high resolution model development for the Southern Rocky Mountains. More compelling is the evidence that the moisture deficit in soils and streams (likely) will increase. For trout that is likely to mean lower late summer/fall flows.

ii. **Physiological hydrological niche.** Somewhat Increase to Increase. Occupy relatively cold and steep streams at high elevations (currently) (Young 2008; NatureServe 2010; Behnke 1992). The species obviously depends on adequate water supply throughout the year. Drought in the past decade has demonstrated the degree of drying that can be anticipated.

c. **Dependence on a specific disturbance regime.** Somewhat Increase. Fire and flooding are key factors that determine water/habitat quality. Extreme events are known to greatly alter habitat condition including water temperature, water chemistry, degree of sediment, and degree of habitat complexity (Schlosser and Angermeier 1995; Labbe and Fausch 2003; Reeves et al. 1995; Benda et al. 1998).

d. **Dependence on snow-covered habitats.** Neutral.

C3) Restriction to uncommon geological features or derivatives. Neutral. However, waterfalls, a relatively rare geological feature, play a significant role in protecting the species from contact with harmful non-native fish and in limiting the distribution of trout (Young 2008).

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Somewhat Increase. Trout do not depend on beaver, but their presence greatly enhances habitats with deep pools (preventing winter freezing and summer warming) (Chisolm et al. 1987; Lindstrom 2003). In addition, beaver buffer the late summer low flows in a watershed (Naiman, et al. 1986).

b. **Dietary versatility.** Neutral. Will eat what is available even though there is notable selectivity in summer (Young et al. 1997; Hildebrand and Kershner 2004).

C5) Genetic factors.

a. **Measured genetic variation.** Somewhat Increase. Trout generally have high levels of genetic diversity (Allendorf and Leary 1988). However, patterns of variability are strongly correlated with locations (Shiozawa and Evans 2007, unpublished data presented in Young 2008). Within clade variation was high. This could be an adaptation for dealing with highly variable habitats.
b. **Occurrence of bottlenecks in recent evolutionary history** – only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Unknown. No known measured response. However, spring peak runoff is occurring 2-3 weeks earlier than historically. Since spring runoff and water temperature are triggers for spawning, it is possible that there is a response.

D1) Response to recent climate change. Neutral. No published accounts.

D2) Modeled future change in population or range size. Unknown.

D3) Overlap of modeled future range with current range. Unknown.

D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing sites is likely.

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4. MAMMALS

Gunnison Prairie Dog (*Cynomys gunnisoni*)

B1) Exposure to sea level rise. Neutral.

B2) Distribution relative to barriers.

a. **Natural.** Neutral. A combination of low passes in several places in and out of the Gunnison Basin suggest that there are no barriers that will prevent the Gunnison Prairie dog from coming and going over time. Populations are known to have occurred as high as ~12,000' elevation in Colorado (Fitzgerald et al. 1994). However, the USFWS (2008) pointed out that numerous parts of the range are separated by mountain ranges that almost completely limit prairie dog movement between them. Habitat models and connectivity analyses would provide more insights into the degree to which the individual populations of this species are isolated. Clearly with the effects of poisoning and plague, the greatly reduced populations are much more isolated from one another than occurred prehistorically.
b. **Anthropogenic.** Neutral. Most of the area in Gunnison Valley is public land available to the prairie dogs. The reservoir presents a significant barrier as does the river proper when large. However, prairie dogs current exist on both sides of the river and reservoir. While Gunnison prairie dogs are not common in the town of Gunnison, they appear to thrive on the outskirts of town all the way around.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. Although it is expected that additional residential development will occur in the Gunnison Valley, it is unlikely that the growth is related to climate change.

C1) Dispersal and movements. Somewhat Decrease. The movements and dispersal are poorly studied in this species. However, in other species of prairie dogs movements are known to be around 2-8 km (or occasionally more in the black-tailed prairie dog) (Garrett and Franklin 1988; Knowles 1985). Seglund and Schnurr (2010) reported dispersal distances as long as 4.8 miles.

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
   i. **Historical Thermal Niche.** Neutral. (NatureServe Climate Change Vulnerability Index factor C2ai (2010). – see map provided by NatureServe.
   ii. **Physiological Thermal Niche.** Neutral. Temperature does not appear to be a major determinant of habitat for the Gunnison prairie dog since the Gunnison Valley, the San Luis Valley, North Park, and other cold air sink valleys of central Colorado are inhabited. This species does hibernate during several months during late fall and early winter (Shalaway and Slobodchikoff 1988)
b. **Hydrology**
   i. **Historical Hydrological Niche.** Somewhat Increase. Historical precipitation has varied from wetter cycles to drier cycles (ClimateWizard online).

ii. **Physiological hydrological niche.** Neutral to Somewhat Decrease. Gunnison's prairie dog is tolerant of dry to fairly moist conditions (see distribution map of the species). However, vegetation condition of many lands within the range of Gunnison's prairie dog has been altered largely through grazing (Fleischner 1984). The prairie dogs are possibly more susceptible to stress from drought where native vegetation has been severely altered (Seglund and Schnurr 2010). The hydrological regime cannot support abundant trees and therefore in many mountain parks where precipitation is quite low, the prairie dog has usually occurred.

c. **Dependence on a specific disturbance regime.** Somewhat Increase to Increase. Gunnison's prairie dogs (and other species as well) are occasionally exposed to drought conditions. These conditions cause stress and even population reduction/extirpation in the black-tailed prairie dog (Facka et al. 2010). Climate data suggest that drought will possibly increase in frequency, intensity and duration. Plague is also a significant disturbance to this species.

d. **Dependence on snow-covered habitats.** Neutral. There is no known relationship of this species to snow or ice-covered habitats.

C3) Restriction to uncommon geological features or derivatives. Neutral. This species is not known to specialize on uncommon geological features.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Neutral. Generates its own habitat by burrowing.

b. **Dietary versatility.** Neutral. Gunnison's prairie dog is a vegetarian, feeding largely on grasses and forbs, supplementing this diet with some shrubs (Fitzgerald and Lechleitner 1974; Longhurst 1944).

C5) Genetic factors.

a. **Measured genetic variation.** Neutral. Genetic diversity in this species was determined to be low (Travis, Slobodchikoff, and Keim 1997). Reports are not available for montane populations in Colorado. Mexican black-tailed prairie dogs occur in somewhat isolated colonies in arid lands and low montane valleys and also show modest variability and little differentiation among subpopulations (McCullough and Chesser 1987).

b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Neutral. No observations made.

D1) Response to recent climate change. Neutral. Nothing reported.

D2) Modeled future change in population or range size. Unknown.

D3) Overlap of modeled future range with current range. Unknown.

D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new sites is likely.

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Wolverine (*Gulo gulo*)
B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers. No barriers
B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Long-distance disperser (>30 km in one night; Wilson 1982).
C2) Sensitivity to temperature and moisture changes. Within the study area, this species is restricted to high-elevation environments, increasing its physiological thermal niche vulnerability. Highly dependent upon spring snow cover (Copeland et al. 2010).
C3) Restriction to uncommon geological features or derivatives. Not tied to any specific geologic feature.
C4) Reliance on interspecific interactions. Wolverines eat a variety of plant and animal matter, but in winter diet is mostly carrion and mammals (Fitzgerald et al. 1994).
C5) Genetic factors.

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Snowshoe Hare (*Lepus americanus*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers.

a. **Natural.** Somewhat Increase. This species is limited to relatively high elevations from 8,000 – 11,500 feet (Fitzgerald et al. 1994) and therefore restricted to mountain forests. Barriers to dispersal include unforested areas, steep slopes, rocky and rough terrain, fast-moving rivers, and urban areas (Ellsworth and Reynolds 2006). Sagebrush and pinon-juniper vegetation is not suitable. No barriers into the extensive mountainous regions north and east of the study area. It is notable that snowshoe hares occur down to 6,500 feet in Gunnison County.
b. **Anthropogenic.** Neutral. A few large roads and some residential development into the lower reaches of their range (e.g., Crested Butte). No significant barriers of human origin.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. Most of the suitable habitat for this species in the Gunnison Basin is public land where management is expected to continue largely for conservation purposes.

C1) Dispersal and movements. Somewhat Decrease. Snowshoe hares generally stay within a relatively small area during their life. Average movements are less than 2 km; however, maximum movements are up to 20 km (Hodges 1998; Gillis and Krebs 1999; Ellsworth and Reynolds 2006).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**
    i. **Historical Thermal Niche.** Neutral. (NatureServe Climate Change Vulnerability Index factor C2ai (2010). – see map provided by NatureServe. NOTE: Large scale averages as seen in the referenced map may not indicate the degree of variability in a mountainous landscape such as in this study area.
    ii. **Physiological Thermal Niche**. Increase. This species depends on mature forests with patches of successional habitat (Ellsworth and Reynolds 2006) and abundant winter snow (University of Montana 2009)
b. **Hydrology**

i. **Historical Hydrological Niche.** Neutral. High variability in winter precipitation is characteristic of the region; however, the Gunnison area is more xeric than much of the rest of the Southern Rocky Mountains.

ii. **Physiological hydrological niche.** Increase. Ray et al. (2008) claim that more winter rain, earlier meltoff, and less winter snow in some years could expose hares to high levels of stress (University of Montana 2009).

c. **Dependence on a specific disturbance regime.** Somewhat Increase to Increase. Snowshoe hares depend on older growth subalpine forests with patches of younger growth (Ellsworth and Reynolds 2006; Fitzgerald et al. 1994). The extant fire regime appears to maintain such habitat in much of the study area, creating younger patches of trees with more dense undergrowth. However, increased fire frequency in high elevation forests may change that balance and degrade habitat quality over large areas. Ellsworth and Reynolds (2006) note the risk to hares from climate shifts that reduce the amount of spruce and fir forests. Dale et al. (2001) noted the potential for increased drought stress, fire frequency, and tree mortality from insects – all negatively impacting hares.

d. **Dependence on snow-covered habitats.** Increase. Winter snow cover is critical to the snowshoe hare (Ellsworth and Reynolds 2006; NatureServe 2010; Fitzgerald et al. 1994; University of Montana 2009).

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4) Reliance on interspecific interactions

a. **Dependence on other species to generate habitat.** Neutral. The snowshoe hare does not depend on any other species to generate or perpetuate its habitat.

b. **Dietary versatility.** Neutral. The diet of snowshoe hares is seasonably variable within its habitat, being composed of mostly herbaceous material in the summer and woody types in the winter (Ellsworth and Reynolds 2006).

C5) Genetic factors.

a. **Measured genetic variation.** Neutral. Burton et al. (2002) found that hares in the northern boreal forests have high genetic variability and low segregation of populations. No comparable information is available for southern populations.

b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Somewhat Increase to Increase. Pelage color changes may become out of synch with precipitation patterns (University of Montana 2009; Kielland et al. 2010).

D1) Response to recent climate change. Neutral. Responses to climate change are not available, especially for the Southern Rocky Mountains.

D2) Modeled future change in population or range size. Somewhat Increase. While there are no models of hare populations for the future, there are habitat models that predict extensive changes in distribution and extent of primary habitat (Dale et al. 2002).

D3) Overlap of modeled future range with current range. Unknown.

D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, conservation management of existing and new sites is likely.

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Species Name: Lynx (*Lynx lynx*)

B1) Exposure to sea level rise. Neutral.

B2) Distribution relative to barriers.

a. **Natural.** Somewhat Increase. Sagebrush, grasslands, and open, lower elevation, savanna-like vegetation are likely natural barriers or at least strong filters to change of distribution. However, see the notes on dispersal for more information on how much leakage there is in what we think of as barriers.

b. **Anthropogenic.** Somewhat Increase. Only the reservoir is a major barrier for lynx dispersal. In addition there are several paved highways that would serve as filters but not barriers.

B3) Impact of land use changes resulting from human responses to climate change. Neutral. Most of the current habitat for the lynx is in rugged, publicly owned lands. It is not expected that land use will change significantly at elevations above 9,000'

C1) Dispersal and movements. Decrease. Lynx have large home ranges in Colorado (75.2 km^2 – 145.4 km^2 Shenk (2009)). Average dispersal in Montana and Wyoming are less than 8 km (Squires and Laurion 1999). However, one individual that was captured in Canada, released into Colorado where it remained for four years, traveled 1,200 miles back to Alberta (Pankratz 2010).

C2) Sensitivity to temperature and moisture changes.

a. **Temperature**

   i. **Historical Thermal Niche.** Neutral. (NatureServe Climate Change Vulnerability Index factor C2ai (2010). – see map provided by NatureServe. NOTE: the coarse scale of the North American assessment may not accurately reflect local conditions in the Gunnison Valley, especially in the mountainous regions of western Colorado.

   ii. **Physiological Thermal Niche.** Increase. The lynx is almost exclusively found in high elevation, cool forests in Colorado – primarily the spruce-fir and aspen forests (Shenk 2009). The presence of snow in this habitat is important for lynx and its prey, the snowshoe hare.

b. **Hydrology**

   i. **Historical Hydrological Niche.** Neutral to Somewhat Increase. The mountains of central Colorado have highly variable precipitation from year to year. (Ray et al. 2008). But this variation may not capture the degree to which variation in snowfall is expected in the next 50 years.

   ii. **Physiological hydrological niche.** Neutral to Somewhat Increase. The lynx depends on snowfall in the winter, especially if it is deep enough to reduce competition from other predators of the snowshoe hare.

c. **Dependence on a specific disturbance regime.** Increase. The lynx favors dense spruce-fir forests (Shenk 2009) and early successional forests after fire or cutting (Fitzgerald et al. 1994). If the fire frequency is too low, then the habitat for higher densities in hares is relatively unavailable. If the fire frequency is too high, there is inadequate dense cover during winter.

d. **Dependence on snow-covered habitats.** Increase. As noted above, deep snow is necessary for lynx to reduce competition and to enable rapid movement across the snow.

C3) Restriction to uncommon geological features or derivatives. Neutral.

C4) Reliance on interspecific interactions.

a. **Dependence on other species to generate habitat.** Neutral. No such relationship is known.

b. **Dietary versatility.** Somewhat Increase to Increase. A wide range of small mammals and birds occur in this species' diet (Fitzgerald et al. 1994); however, lynx in Colorado consume mostly hares and some squirrels (Shenk 2009).

C5) Genetic factors.

a. **Measured genetic variation.** Somewhat Increase. Schwartz et al. (2003) found that edge of range populations of lynx had fewer numbers of alleles per population and lower than expected heterozygosity.

b. **Occurrence of bottlenecks in recent evolutionary history.** Only if 5A is unknown.

C6) Phenological response to changing seasonal temperature and precipitation dynamics. Neutral.

D1) Response to recent climate change. Neutral.

D2)Modeled future change in population or range size. Somewhat Increase. No such models located; however, there are models for spruce-fir and aspen that suggest the degree to which the habitat (and therefore the range size) may change.

D3) Overlap of modeled future range with current range. Unknown.

D4) Protected areas. Neutral. Many of the current and potential nesting sites are in some form of protected status, particularly as publicly managed lands (TNC, Measures Report). As such, management of existing and new occurrences is likely.

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American Pika (*Ochotona princeps*)

B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers. Barriers (both anthropogenic and natural) thought to be neutral due to elevation range at which this species is found (above 10,000 feet; Fitzgerald et al. 1994). Major rivers and large highways not present at high elevations.
B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Maximum dispersal is typically 3 km based on a study in the Great Basin by Smith (1974), but greater distances in the more mesic Rocky Mountains are thought to be possible (Hafner 1994).
C2) Sensitivity to temperature and moisture changes. Species requires cool areas and exhibit higher occupancy around water and willows. High temperatures can be lethal (Smith 1974) and warm days may reduce time spent foraging (Smith 1974; Smith and Weston 1990). Field experiments have shown that adults were killed within a half hour at temperatures greater than 31° C (Smith 1974).
C3) Restriction to uncommon geological features or derivatives. This species is considered to be a near obligate of talus habitat (Smith and Weston 1990) and rely on this feature for dens, nests, and haypile caches. In their model-selection analysis using univariate regression to select variables to include, Beever et al. (2003) found that the amount of talus habitat present at a coarse scale was the strongest predictor of pika persistence.
C4) Reliance on interspecific interactions. This species is a generalist herbivore (Smith and Weston 1990).
C5) Genetic factors. Pika have low levels of genetic heterozygosity compared to other wide-ranging mammals (Tolliver et al. 1985).
D1) Documented response. A study in the Great Basin, revealed that 7 out of 25 recensused populations of pika were extinct since being recorded in the 1930s; most of these extinct populations were at lower elevations than extant populations (Beever et al. 2003). However, recent work indicates that the population extinctions observed in the Great Basin are not taking place within Colorado. Surveys conducted in 2008 throughout Colorado, including the Gunnison Basin, revealed that most (93.5%) of historic sites (pre-1980) supported pika and there was no indication of extirpation at lower elevations (CDOW 2009).

Literature Cited

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Tolliver, D.K., M.H. Smith, P.E. Johns, and M.W. Smith. 1985. Low levels of genetic variability in pikas from Colorado. Canadian Journal of Zoology 63:1735-1737.

Townsend's big-eared bat (*Corynorhinus townsendii pallescens*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers. Volant - no barriers

B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements. Long-distance dispersal ability.

C2) Sensitivity to temperature and moisture changes.

C3) Restriction to uncommon geological features or derivatives. This bat is a cave/mine obligate, but is found in mines more frequently than caves.

C4) Reliance on interspecific interactions. This species is a moth specialist, but will feed opportunistically on other flying insects (Gruver and Keinath 2006).

C5) Genetic factors. In an analysis of genetic diversity among subspecies of COTO, Piaggio et al. (2009) found that *C. t. pallescens* had a level of diversity similar to *C. t. townsendii* and both of these subspecies had a greater level of diversity than the endangered *C. t. virginianus* as measured by the average number of alleles per locus and average allelic richness per population.

Literature Cited

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Pygmy Shrew (*Sorex hoyi montanus*)

B1) Exposure to sea level rise. Neutral

B2) Distribution relative to barriers. Barriers (both athropogenic and natural) thought to be neutral due to elevation range at which this species is found (9,600-11,100; Siemers 2009; Fitzgerald et al. 1994). Major rivers and large highways not present at high elevations. High mountain passes not thought to be barriers to dispersal.

B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.

C1) Dispersal and movements.

C2) Sensitivity to temperature and moisture changes. Species likes cool areas. Montane environment is expected to move up in elevation, but not out of the study area. For hydrological niche, species prefers moist habitats. Areas within the range are likely to experience drying, which will decrease habitat quality and possibly quantity. Increased fire is thought to negatively affect this species by reducing habitat quality and quantity.
C3) Restriction to uncommon geological features or derivatives. Not tied to any specific geologic feature.
C4) Reliance on interspecific interactions.
C5) Genetic factors. Unknown
Literature Cited
Fitzgerald, J.P., C.A. Meaney, and D.M. Armstrong. 1994. Mammals of Colorado. Denver Museum of Natural History and University Press of Colorado. 467 pp.

Siemers, J.L. 2009. Pygmy shrew (*Sorex hoyi montanus*) survey on the White River National Forest.

Dwarf Shrew (*Sorex nanus*)
B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers. Barriers (both athropogenic and natural) thought to be neutral due to elevation range at which this species is found (5,500 to over 10,000 feet); Major rivers and large highways are present at lower elevations within the study area, but species is found throughout the area.
B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements.
C2) Sensitivity to temperature and moisture changes. Species likes cool areas, but is not as restricted to high elevations as other species. For hydrological niche, species prefers moist habitats but can also be found in relatively arid locations away from water (Fitzgerald et al. 1994). Areas within the range are likely to experience drying, which will decrease habitat quality and possibly quantity. Increased fire is thought to negatively affect this species by reducing habitat quality and quantity.
C3) Restriction to uncommon geological features or derivatives. Not tied to any specific geologic feature.
C4) Reliance on interspecific interactions.
C5) Genetic factors.
Literature Cited
Fitzgerald, J.P., C.A. Meaney, and D.M. Armstrong. 1994. Mammals of Colorado. Denver Museum of Natural History and University Press of Colorado. 467 pp.

Bighorn Sheep (*Ovis canadensis*)
B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers. No barriers (e.g. large rivers) within this species' range in the study area.
B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements. Long-distance dispersal ability.

C2) Sensitivity to temperature and moisture changes. Grasslands in which this species is found are often fire-maintained (Geist 1971; Erickson 1972) and as fire frequency increases due to climate change, habitat quality may also increase. Prefers snow-free or shallow (<30 cm) areas (Stelfox 1975).
C3) Restriction to uncommon geological features or derivatives. Suitable escape terrain (cliffs, talus slopes) is an important habitat feature (Oldemayer et al. 1971; Erickson 1972; Pallister 1974) as are mineral licks (Shackleton et al. 1999; Krausman et al. 1999).
C4) Reliance on interspecific interactions. Diet is diverse, consisting of grasses, grass-like plants, browse, and some forbs (Fitzgerald et al. 1994).
C5) Genetic factors.

<u>Literature Cited</u>

Erickson, G. L. 1972. The ecology of Rocky Mountain bighorn sheep in the Sun River area of Montana with special reference to summer food habits and range movements [thesis]. Bozeman, MT, USA: Montana State University. 50 pp.

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Oldemeyer, J.L., W.J. Barmore, and D.L. Gilbert. 1971. Winter ecology of bighorn sheep in Yellowstone National Park. *Journal of Wildlife Management* 35:257- 269.

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Shackleton, D.M., C.C. Shank, and B.M. Wikeem. 1999. Natural history of Rocky Mountain and California bighorn sheep. *In:* R. Valdez and P.R. Krausman, eds. Mountain sheep of North America. Tucson, AZ, USA: University of Arizona Press. p. 78-138.

5. INSECTS

Uncompahgre Fritillary (*Boloria improba acrocnema*)
B1) Exposure to sea level rise. Neutral
B2) Distribution relative to barriers. Barriers (both anthropogenic and natural) thought to be neutral due to elevation range at which this species is found (above 12,100 feet).
B3) Impact of land use changes resulting from human responses to climate change. It is unlikely that any mitigation-related land use changes will occur within this species' range within the study area.
C1) Dispersal and movements.

C2) Sensitivity to temperature and moisture changes. Species likes cool areas and is completely restricted to cold environments (north-facing slopes at high elevation) in the study area. For hydrological niche, species prefers moist habitats and is somewhat dependent on localized moisture regime. Areas within the range are likely to experience drying, which will decrease habitat quality and possibly quantity.
C3) Restriction to uncommon geological features or derivatives. Not tied to any specific geologic feature.
C4) Reliance on interspecific interactions. Snow willow (*Salix reticulata* spp. *nivalis*) is the exclusive larval food plant. Adults feed on nectar from a wide range of flowering alpine plants (USFWS 2011).
C5) Genetic factors. Britten and Brussard (1992) determined that this butterfly is distinct from other closely related species. Research is currently being undertaken on genetic homogeneity among the 11 known colonies (USFWS 2009).

<u>Literature Cited</u>

Britten, H.B. and P.F. Brussard. 1992. Genetic divergence and Pleistocene history of the alpine butterflies *Boloria improba* (Nymphalidae) and the endangered *Boloria acrocnema* (Nymphalidae) in Western North America. Canadian Journal of Zoology 70:539-548.

U.S. Fish and Wildlife Service (USFWS). 2011. Uncompahgre Fritillary Butterfly (*Boloria acrocnema*) Species Profile. Environmental Conservation Online System. http://ecos.fws.gov/speciesProfile/profile/speciesProfile.action?spcode=I01Q

U.S. Fish and Wildlife Service (USFWS). 2009. Uncompahgre Fritillary Butterfly (*Boloria acrocnema*) 5-year Review: Summary and Evaluation. U.S. Fish and Wildlife Service Western Colorado Field Office.

APPENDIX I: Species Considered, but not Included, on Project Species List

Latin Name	**Common Name**	**Reason**
PLANTS		
Adiantum capillus-veneris	Southern maidenhair fern	No known occurrences in study area
Arnica alpina var. tomentosa	Alpine arnica	No known occurrences in study area
Askellia nana	Dwarf alpine hawk's-beard	No known occurrences in study area
Asplenium trichomanes-ramosum	Green spleenwort	Only known from historic or general record(s)
Aster alpinus var. vierhapperi	Alpine aster	Only known from historic or general record(s)
Astragalus brandegeei	Brandegee milkvetch	Only known from historic or general record(s)
Braya humilis	Alpine braya	No known occurrences in study area
Carex viridula	Green sedge	No known occurrences in study area
Cryptogramma stelleri	Slender rock-brake	No known occurrences in study area
Cystopteris montana	Mountain bladder fern	No known occurrences in study area
Draba crassa	Thick-leaf whitlow-grass	Only known from historic or general record(s)
Draba exunguiculata	Clawless draba	Only known from historic or general record(s)
Draba graminea	San Juan whitlow-grass	Only known from historic or general record(s)
Draba incerta	Yellowstone whitlow-grass	No known occurrences in study area
Draba oligosperma	Woods draba	No known occurrences in study area
Draba porsildii	Porsild's whitlow-grass	Only known from historic or general record(s)
Draba ventosa	Tundra draba	Only known from historic or general record(s)
Iliamna grandiflora	Large-flower globe-mallow	Only known from historic or general record(s)
Listera borealis	Northern twayblade	Only known from historic or general record(s)

Latin Name	Common Name	Reason
Lomatium concinnum	Colorado desert-parsley	No known occurrences in study area
Lupinus crassus	Payson lupine	No known occurrences in study area
Muscaria monticola	Tundra saxifrage	No known occurrences in study area
Salix lanata ssp. calcicola	Lime-loving willow	Only known from historic or general record(s)
Stellaria irrigua	Altai chickweed	Only known from historic or general record(s)
Thelypodiopsis juniperorum	Juniper tumble mustard	Only known from historic or general record(s)
Trichophorum pumilum	Little bulrush	No known occurrences in study area
BIRDS		
Athene cunicularia	Burrowing Owl	Only one individual known to nest in study area
Dendroica graciae	Grace's Warbler	Not known to occur in study area; would be covered by Ponderosa pine ecological system.
Grus canadensis tabida	Greater Sandhill Crane	Not nesting in study area
Coccyzus americanus	Yellow-billed Cuckoo	Not known to nest in study area; would be covered by riparian ecological system analysis
FISH		
Catostomus discobolus	Bluehead sucker	No pure extant populations remaining in the project area
Catostomus latipinnis	Flannelmouth sucker	No pure extant populations remaining in the project area
Gila robusta	Roundtail chub	No evidence of occurrence above the Black Canyon
Catostomas platyrhynchus	Mountain sucker	Likely misidentified
MAMMALS		
Lepus townsendii	White-tailed jackrabbit	Not known to occur in study area
INSECTS		
Lycaeides idas sublivens	Dark blue	Insufficient information
Oeneis bore	White-veined Arctic	Insufficient information

Latin Name	**Common Name**	**Reason**
MOLLUSKS		
Ferrissia walkeri	Cloche ancylid	Insufficient information, questionable occurrence in the Basin, taxonomic uncertainty
Promenetus umbilicatellus	Umbilicate sprite	Insufficient information

APPENDIX J: Participants of the Vulnerability Assessment Review Workshops
(May, July, and October 2011)

Organization	Last Name	First Name
BLM	Austin	Gay
BLM	Breibart	Andrew
BLM	Fresques	Tom
BLM	Homstad	Kelly
BLM	St. George	Brian
CCWC	Poponi	Anthony
CNHP	Kuhn	Bernadette
CNHP	Rondeau	Renee
CNHP	Siemers	Jeremy
CPW	Brauch	Dan
CPW	Jones	Paul
CPW	Seglund	Amy
CPW	Seward	Nathan
CPW	Wenum	J.
GCO	Cochran	James
HCCA	Glazer	Steve
LFVC	Richard	Camille
NPS	Childers	Theresa
NPS	Malick	Matt
NPS	Stahlnecker	Ken
NRCS	Scott	John
NRCS	With	Liz
RMBL	Billick	Ian
TNC	Babler	Mike
TNC	McCarthy	Patrick

Organization	Last Name	First Name
TNC	Neely	Betsy
TNC	Pague	Chris
TNC	Robertson	Jamie
TNC	Sanderson	John
TNC	Schulz	Terri
UAF	Knapp	Corrie
UGRWCD	Kugel	Frank
USFS RMRS	Battaglia	Mike
USFS	Bethers	Suzanne
USFS	Howe	Carol
USFS	Johnston	Barry
USFS RMRS	Joyce	Linda
USFS	Murphy	John
USFS	Regan	Claudia
USFS	Stratton	Ben
USFS	Vasquez	Matt
USFWS	Pfister	Al
USFWS	Reinkensmeyer	Dan
WSC	Alexander	Kevin
WSC	Coop	Jonathan
WSC	Magee	Pat
WWA	Rangwala	Imtiaz
WWA	Barsugli	Joe
Gunnison	Lehr	Paula

KEY	
BLM	Bureau of Land Management
CCWC	Coal Creek Watershed Coalition
CPW	Colorado Parks & Wildlife
CNHP	CO Natural Heritage Program
CU	University of Colorado
GCO	Gunnison County
HCCA	High Country Citizens Alliance
LFVC	Lake Fork Valley Conservancy
NPS	National Park Service
NRCS	Natural Resources Cons. Service

KEY	
RMBL	Rocky Mountain Biological Lab.
TNC	The Nature Conservancy
UAF	University of Alaska Fairbanks
UGRWCD	Upper Gunnison River Water Conservancy District
USFS	US Forest Service
USFS RMRS	USFS Rocky Mtn. Research Sta.
USFWS	US Fish and Wildlife Service
WSC	Western State College
WWA	Western Water Assessment